UNIVERSITY OF CALIFORNIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

Irrigation Water Requirement Studies of Citrus and Avocado Trees in San Diego County, California, 1926 and 1927

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BULLETIN 489
April, 1930

UNIVERSITY OF CALIFORNIA PRINTING OFFICE
BERKELEY, CALIFORNIA
1930

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INTRODUCTION

This bulletin presents the results of a two years' study dealing with the irrigation water requirements of citrus and avocado trees in the coastal plains area and interior valleys of northern San Diego County, California, and is the first report on an extended investigation of the economic field duty of water in southern California. The study has for its primary objects the determination of the quantity of irrigation water required for successful crop production in the principal irrigated areas of that section and the ascertainment of the safe economic water requirement under which irrigation districts and mutual water companies may be organized.

The investigations of the economic field duty of water in southern California, of which this bulletin is the first of a series of reports, are conducted cooperatively by the Division of Irrigation Investigations and Practice of the College of Agriculture; the Division of Agricultural Engineering, Bureau of Public Roads, United States Department of Agriculture; and the Division of Water Resources, California State Department of Public Works. During the conduct of the investigation the Director and several of the specialists of the Citrus Experiment Station at Riverside were frequently consulted.

GENERAL DESCRIPTION OF THE AREA

The part of San Diego County covered by this report includes the areas lying within the San Dieguito, San Luis Rey and Santa Margarita watersheds and along the intervening and adjacent minor coastal streams. In general, the area is mountainous and rugged, containing numerous sharply outlined interior valleys, fringed by a narrow coastal plain. Within this area, profitable crop production is almost entirely dependent upon irrigation.

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The present irrigation water supply is dependent upon storage on the three major rivers and upon a limited additional underground supply made available by pumping from the valleys and bottom lands bordering these rivers and the minor coastal streams. The problem of storage is complicated by wide fluctuations in seasonal precipitation which give rise to erratic, 'flashy,' and widely fluctuating stream flow. Stored water is distributed through organized irrigation districts and mutual water companies; the major portion of the pumping is done by private enterprise.

The soils of the area have been classified[4] into three groups, which include: (1) the residual soils (loams, sandy loams, etc.) of the Sierra, Holland, and Aiken series derived through the disintegration or weathering in place, of consolidated rocks; (2) soils derived through the weathering and other modifications of old, unconsolidated, water-laid deposits, including the Montezuma adobes, the Kimball sandy loams, and the various types of the Las Flores, Placentia, and Redding series; (3) recent alluvial loams, sandy loams, and sands of the Yolo, Hanford, and Foster series, which are deposited at or near the present stream channels or as alluvial fans.

The area as a whole includes some 870,000 acres, 230,000 of which may be classed as agricultural land. Of the latter approximately 100,000 acres is irrigable and of such quality as to warrant consideration in future development and utilization of the water supply. A survey of the area in 1928 showed a total of 17,400 acres under irrigation.

The climate is featured by a rainless season extending from the middle of April to about the middle of November, the normal irrigation season extending to about the middle of October. The winter rainfall averages 10 to 12 inches on the coastal plain area and 16 to 17 inches in the interior valleys. Moderate temperatures prevail in the summer, with occasional hot desert winds in the interior valleys. Table 1 shows a comparison of temperatures and rainfall at Oceanside, Escondido, and Fallbrook for the years 1900 to 1924.

The principal crops are citrus fruits, avocados, grapes, truck crops, and bulbs. Of the citrus fruits, lemons occupy most of the present acreage, although in recent plantings oranges predominate. The citrus fruits are mainly confined to the interior valley areas and rolling foothills adjacent to the coastal plain. Avocados are fast coming into prominence, especially on the newly developed areas of the coastal

[4] Holmes, L. C. Reconnaissance soil survey of the San Diego region, California. Bureau of Soils, U. S. Dept. of Agriculture. 1918.

plains and adjacent foothills. Truck crops (celery, tomatoes, beans, peas, etc.) and bulbs are confined principally to the coastal plain.

The area is characterized by an abundance of irrigable land and a limited irrigation water supply. In its agricultural development the available water supply should be utilized to the maximum and the yearly water allowance should be based, as far as possible, on the actual requirements of the crops, with the irrigation water applied under reasonably efficient irrigation practice.

TABLE 1

Summary of Temperature and Rainfall Records at Oceanside, Escondido, and Fallbrook, 1900–1924

Locality	Temperature (degrees Fahrenheit)								Seasonal rainfall, inches		
	25-year average						Highest recorded	Lowest recorded			
	Maximum		Minimum		Mean				Maximum	Minimum	Average, 25 years
	Range	Average	Range	Average	Range	Average					
Oceanside	61 to 75	68.5	45 to 64	53.6	54 to 69	61.4	106	21	19.8	5.7	12.9
Escondido	64 to 89	76.2	35 to 56	45.1	50 to 72	60.8	113	13	28.4	7.9	16.4
Fallbrook									28.6	8.7	17.1

CROPS, SOIL TYPES, AND LOCATION OF EXPERIMENTAL PLOTS

During the 1926 season, the crops selected were oranges, lemons, and avocados. In 1927, the observations were continued with these same crops on a more intensive scale. With the exception of truck crops and grapes these are the predominating irrigated crops of the area. Deciduous fruits, because of their smaller returns, are not favored. Alfalfa, field crops, and dairying occupy a very limited acreage.

The predominating soils of agricultural value within the area are the residual sandy loams and loams of the Sierra, Holland, and Aiken series, and the Kimball and Placentia series derived through the weathering and uplifting of the old water-laid deposits. The investigations were therefore confined to these types.

In order to obtain a wide range in climatic conditions, experimental areas were selected in the Fallbrook, Escondido, and Vista localities. The first two are representative of conditions found in the interior valleys, while the Vista section is typical of the rolling foothill areas adjacent to the coastal plain.

Figure 1 shows the general location of the 1926 and 1927 experimental fields.

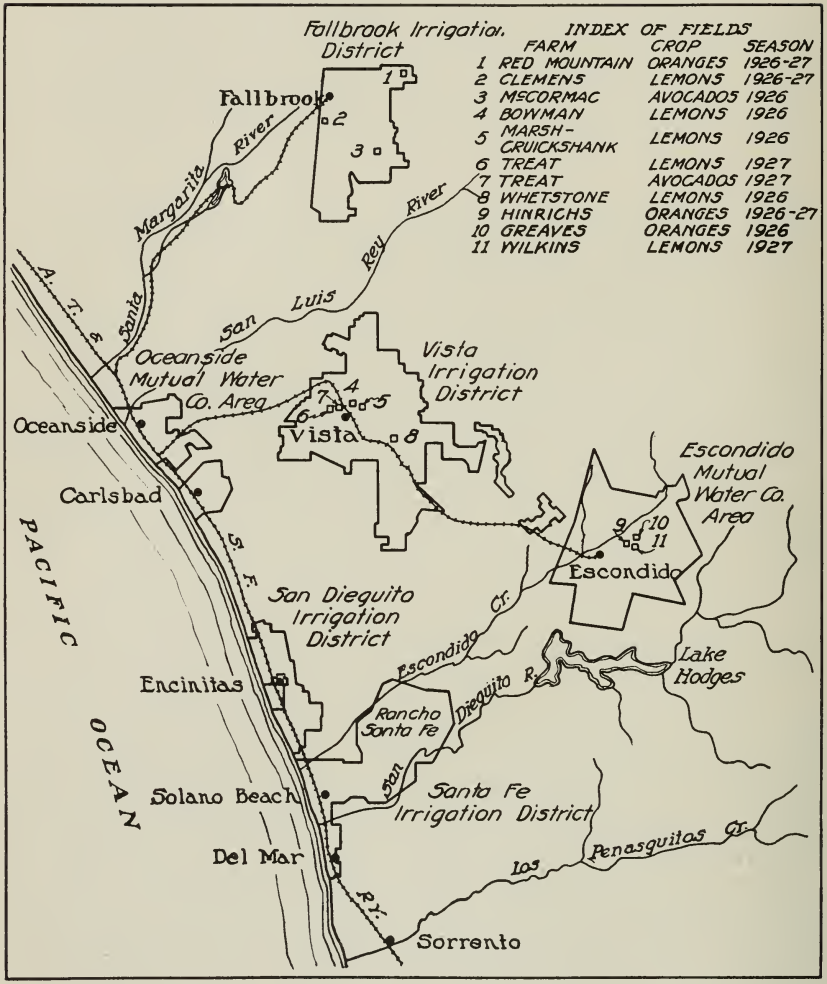


Fig. 1.—Northern San Diego County, showing location of experimental fields, seasons of 1926 and 1927.

METHODS OF PROCEDURE

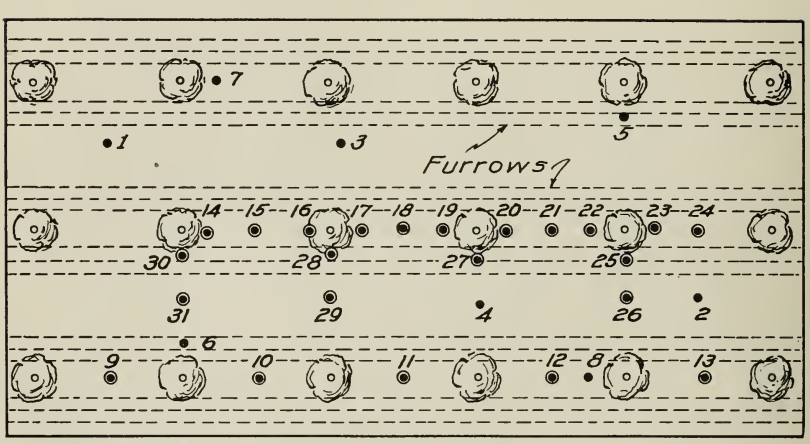
Typical orchards were selected in which the quantity of water used, the frequency of irrigation, the method of irrigation, and other factors represented standard practice of the locality. The quantity of water delivered to each farm at each irrigation was measured, and by frequent sampling of the soil for moisture content in the selected plots, a full season's record of the soil-moisture fluctuations and the rate of moisture extraction from the soil at various depths was obtained.

The records of water measurements and of soil-moisture determinations were used as a basis in determining the following for each grove and for each plot: (1) the rate of use of water and the soil depths from which this water was taken; (2) the monthly and seasonal use of water by the crop under observation; (3) the percentage of water applied which could be accounted for in soil-moisture increase; (4) the monthly and seasonal irrigation requirements; and (5) the required frequency of irrigation, and depth of water to be applied at each irrigation on various soil types.

Selection of Plots.—The following factors governed the selection of field plots: (1) evenness of topography and uniformity of soil; (2) general condition of the grove, and uniformity of trees within the plot; (3) conditions of water delivery, especially facilities for measurement; (4) absence of underground water table; (5) willingness of the water-user to cooperate.

It was originally planned that the area of each of the experimental plots should be one-quarter acre, and should include eight permanently located points of soil sampling within each plot, with such additional sampling as might be necessary to obtain a complete seasonal record of soil moisture fluctuations. The analysis of the data obtained by this method in 1926 showed certain inconsistencies in the soil-moisture determinations. These were attributed to variations in soil type within the quarter-acre plots and to the fact that the samples taken were insufficient in number to counteract these variations. As a result, at the beginning of the season of 1927 the area of each plot was reduced to one-fortieth acre, with from 17 to 30 points of sampling within the plot. In each case, the experimental plot was chosen after a very careful examination of the soil, uniformity of depth and texture being the determining factors. Moisture-equivalent determinations were used as a final check on the uniformity of the texture.

Figure 2 shows the general arrangement of the plots and points of sampling within the plots during 1926 and 1927.



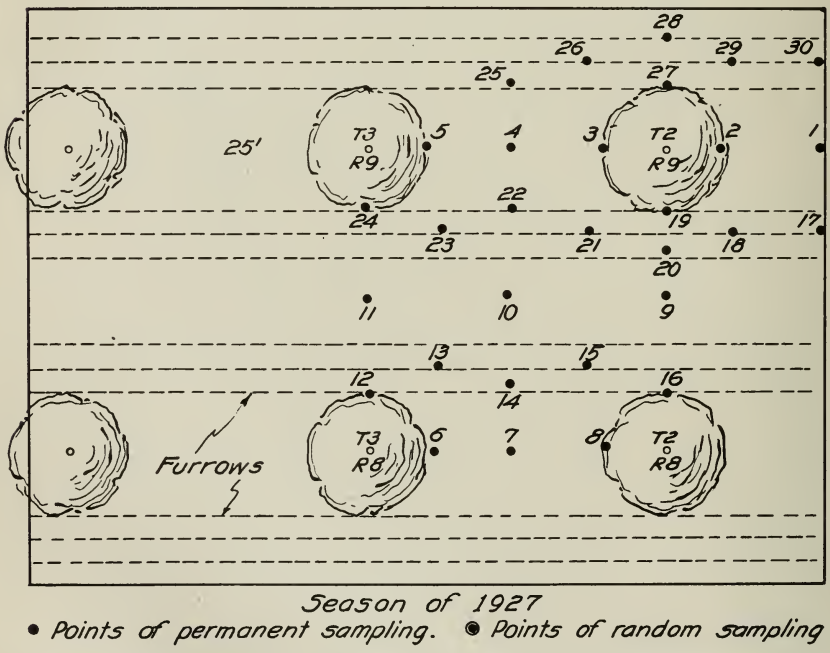


Fig. 2.—The general arrangement of experimental plots and points of soil sampling, seasons of 1926 and 1927.

Measurement of Water.—In the selection of the plots, an effort was made to obtain conditions which would afford an opportunity to measure at each irrigation, the water delivered to the grove, the quantity delivered to the plots, and the run-off from the plots. Except in cases where water was pumped, it was measured when delivered to the farm, either by weirs or through meters used in routine delivery to the user. Because of conditions under which most of the pumps were operating, an almost continuous calibration would have been necessary to obtain reasonable accuracy, and consequently no attempt was made to obtain seasonal records of their discharge.

Where furrow irrigation was practiced, in each case the furrows received water from delivery stands located at the heads of the tree rows. As the quantity of water delivered to the individual furrows was necessarily small, an accurate volumetric measurement was obtained by use of a calibrated container and stop-watch. Waste from the ends of the furrows was measured in a similar manner.

Where portable sprinklers were used, volumetric measurements were made of the discharge of the individual sprinklers. Where sprinklers were of the permanently installed type, a meter measurement of the water applied to the experimental plots was obtained.

Soil Sampling and Computations.—In obtaining soil samples for moisture determinations, the improved soil tube was used.[5] Samples of the soil mulch were treated separately. Below the mulch, samples were taken in 1-foot sections to a depth of 6 feet, unless sampling was prevented by shallowness of the soil or other unfavorable conditions. At the time of final selection of each plot, definite points of soil sampling were established as shown in figure 2. During the irrigation season, samples were taken in the vicinity of each sampling point before and after each irrigation and at intervals of two to three weeks between irrigations. During the winter periods, similar samples were taken after each of the major rains. Standard methods were used in weighing and drying the samples and in computation of moisture percentage. For each period between irrigations in the summer, the moisture content for each foot in depth of soil was plotted as a graph, and a mean or average line was drawn through the points. From this graph the average loss in moisture percentage was obtained for each foot in depth for that period. The total number of acre-inches of water extracted from the soil was computed for each period and later reduced to equivalent losses in acre-inches for a 30-day period. The

[5] Veihmeyer, F. J. An improved soil-sampling tube. Soil Science 27:147–152. 1929.

30-day period losses were then plotted, and a consumptive use of water curve for the season was obtained.[6] The average consumptive use of water for each month was taken directly from the curve. Soil-moisture samples taken before and after each irrigation were used as a basis of computing the increase of water in the soil. A comparison between this quantity and the quantity of water measured on the area establishes the degree of irrigation efficiency, here defined as the percentage of the water applied that is shown in the soil-moisture increase in the zone occupied by the greater portion of the rooting system of the crop; or in other words, as the percentage of water applied that is retained within the principal rooting zone.

Where the furrow method of irrigation was used, it was necessary to obtain a measure of the depth and lateral penetration of the moisture from the furrows. After each irrigation, determinations were made at several points along the length of the furrows within the plot. At each point the soil tube was driven downward vertically, and also diagonally at angles of 30 degrees and 60 degrees on each side. Averages of these measurements were used in plotting the outline of the wetted soil section. The area of this wetted section as obtained from the graph was used as a basis for determining the percentage of the soil mass moistened.

Under conditions of furrow irrigation, there are portions of the soil mass which usually are not moistened by irrigation. This results in forming dry areas or zones in the soil mass. Where the location of the furrows with respect to the tree rows remains unchanged throughout the irrigation season, these wet and dry zones become definitely outlined. Since soil samples were taken from the moistened and unmoistened sections of the plot, it is necessary that they be treated as separate units of soil, and they are referred to in the tables under the heading of moisture percentages in the soil of the irrigated and of the unirrigated sections of the plots, respectively.

Meteorological Observations.—Meteorological observations consisting of temperature, rainfall, and evaporation records were taken at Vista beginning in June, 1926, and continuing through 1927. United States Weather Bureau cooperative observers' records of rainfall and temperatures were available for Escondido, Fallbrook, and Oceanside.

[6] In reducing moisture percentages to equivalent losses in acre-inches per acre, the formula $D = \frac{Pvd}{100}$ was used. In this formula P represents the moisture loss in percentage for the period of time under consideration; v is the apparent specific gravity (often referred to as volume weight); d is the depth of soil in inches; and D is the equivalent depth of water in inches.

TABLE 2

MEAN MONTHLY TEMPERATURES, RAINFALL, AND EVAPORATION AT ESCONDIDO, FALLBROOK, AND VISTA FOR 1925, 1926, AND 1927, TOGETHER WITH 25-YEAR AVERAGE RECORDS FOR SAN DIEGO, OCEANSIDE, AND ESCONDIDO

Station	Period	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean or total
		Mean temperature, degrees Fahrenheit												
San Diego	1900–1924	54.3	55.0	56.9	59.2	61.3	64.8	68.1	69.7	67.9	63.9	59.9	55.7	61.3
Oceanside	1900–1924	54.4	53.8	56.8	59.0	61.2	65.2	68.8	69.4	68.2	64.4	60.5	55.1	61.4
Escondido	1900–1924	50.0	52.1	55.1	58.5	62.5	68.4	72.5	72.4	68.9	62.3	56.1	50.4	60.8
Escondido	1926	50.0	54.4	57.6	61.4	63.1	68.4	70.6	71.6	65.6	64.1	61.2	49.8	61.5
Escondido	1927	51.6	54.0	52.9	56.5	62.0	65.4	72.2	71.1	66.7	63.7	61.2	51.6	60.7
Vista	1926							70.4	72.2	67.0	65.2	63.0	52.5	
Vista	1927	51.6	55.0	54.0	55.8	60.7	63.2	69.8	69.5	66.5	63.4	62.0	52.2	
		Mean rainfall, inches												
San Diego	1900–1924	1.93	1.93	1.49	0.61	0.31	0.06	0.06	0.10	0.08	0.37	0.94	1.75	9.70
Oceanside	1900–1924	3.62	2.39	1.99	0.92	0.22	0.10	0.04	0.02	0.12	0.56	0.96	1.71	12.89
Escondido	1900–1924	4.46	2.92	2.93	1.08	0.61	0.07	0.04	0.09	0.10	0.52	1.29	1.70	16.41
Escondido	1925–1926	0.44	5.79	0.25	8.49	0.02	0.05				4.16	0.93	1.31	21.44
Escondido	1926–1927	0.88	12.83	2.99	0.70	0.82	0.06				0.16	1.61	4.63	24.68
Fallbrook	1900–1924	3.35	3.38	2.99	1.33	0.62	0.11	0.03	0.04	0.10	0.71	1.46	2.88	17.14
Fallbrook	1925–1926	1.39	4.89	0.20	9.20	0.05	0.05				3.29	1.23	1.66	21.96
Fallbrook	1926–1927	0.82	17.25	3.36	0.54	0.39	0.04				0.18	2.23	2.67	27.48
Vista	1925–1926	0.53	4.01	0.44	4.91						3.19	0.90	1.09	15.07
Vista	1926–1927	1.32	8.02	1.99	1.26						0.16	2.23	3.00	17.98
		Mean evaporation from water surface, inches												
Chula Vista	1919–1927	2.84	3.05	4.78	5.48	6.21	6.82	7.31	6.92	5.81	4.57	3.69	2.87	60.38
Vista	1926							8.47	8.77	6.65	5.59	4.29		
Vista	1927	2.29	1.65	3.68	4.94	7.03	6.31	9.66	8.45	6.83	5.09			

In table 2, a comparison is made between the meteorological observations obtained at Escondido, Vista, and Fallbrook during 1926 and 1927, and the mean values obtained from a 25-year record of adjacent observation stations.

Table 2 indicates that during the 1926 and 1927 summer periods the average temperatures showed but a slight departure from the mean of the 25-year period. The two winter periods were abnormal in that the rainfall of each was more than 25 per cent excessive. In each year, fortunately, the rainfall was so distributed that at the beginning of the summer period the soil in all plots was thoroughly moistened to the full depth of root penetration of the trees. Notwithstanding the heavy seasonal rainfall of 1925–26, the distribution was such that a winter irrigation was necessary in January, 1926.

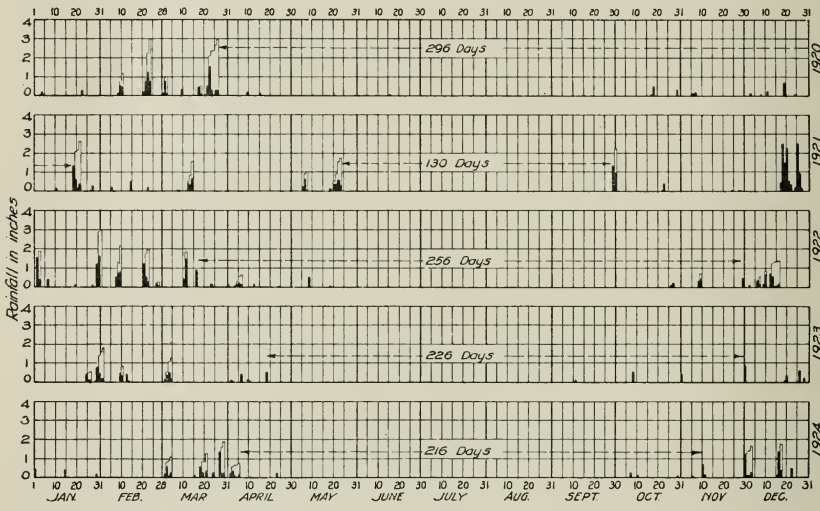


Fig. 3.—Occurrence of rainfall and periods between effective rains, Escondido, California, 1920 to 1924. Shaded blocks show the amount of daily rainfall, unshaded blocks the accumulated rainfall for each storm.

Rainfall records, when plotted as in figure 3, clearly show the wide variation in seasonal rainfall and in its monthly distribution. In this 5-year period the interval between the last effective rain[7] in the spring and the first effective rain in the fall ranged from 130 to 296 days. Over a 25-year period, as shown in table 3, the similar interval ranged from a maximum of 332 days to a minimum of 130 days, averaging 236 days.

[7] An effective rain is here considered as being of such an amount that it materially adds to the moisture supply in the soil area which sustains tree growth.

Table 3 shows that during this 25-year period, where winter cover crops were grown, there were 6 years in which two winter irrigations would have been needed, 8 years in which one winter irrigation was necessary, and 11 years in which no winter irrigation was required.

TABLE 3

OCCURRENCE OF EFFECTIVE RAINS AT ESCONDIDO, 1903–1927, AND NUMBER OF IRRIGATIONS WHICH THEORETICALLY WOULD HAVE BEEN NEEDED IN GOOD PRACTICE, IF COVER CROPS HAD BEEN GROWN

Year	Dates of		Period between effective rains*	Number of irrigations needed†		
	Last effective spring rain	First effective winter rain		Summer	Winter	Total
1903	April 17	January 4	293	3	2	5
1904	March 29	December 21	266	3	1	4
1905	May 8	November 5	181	3	0	3
1906	April 29	November 23	207	3	0	3
1907	March 27	January 23	302	3	2	5
1908	April 23	January 11	263	3	1	4
1909	March 28	November 11	228	3	0	3
1910	March 28	January 9	285	3	2	5
1911	April 11	March 1	332	3	2	5
1912	May 9	January 9	244	3	1	4
1913	March 24	November 12	232	3	0	3
1914	March 30	November 9	223	3	0	3
1915	May 5	December 3	212	3	0	3
1916	March 5	October 1	209	3	0	3
1917	April 16	January 13	268	3	1	4
1918	March 20	November 13	238‡	3	2	5
1919	March 22	October 23	215	3	0	3
1920	March 27	January 17	296	3	2	5
1921	April 23	September 29	130	2	1	3
1922	March 18	November 29	256	3	1	4
1923	April 18	December 1	226	3	0	3
1924	April 7	November 9	216	3	1	4
1925	April 23	October 3	163	2	1	3
1926	April 10	November 24	228	3	0	3
1927	April 12	October 25	196	3	0	3
Average	April 9	November 30	236			

* Rainfall of one-half inch or more is considered as being effective.

† For soils of 3 feet or more in depth, each irrigation being sufficient to moisten the soil to the depth of root penetration.

‡ No rain December 21, 1918, to March 13, 1919.

Similar information obtained from a 45-year record at Fallbrook, beginning with 1875, shows the average interval between the last effective rain in the spring and the first effective rain in the fall to have been 231 days, extending from April 9 to November 25. This interval ranged from a maximum of 309 days in 1876 to a minimum of 129 days in 1921. During this 45-year period, if winter cover crops had been grown, there were 20 years in which no winter irrigation would be needed, 15 years requiring one winter irrigation, and 10 years requiring two.

TABLE 4

DESCRIPTION OF PLOTS SELECTED FOR IRRIGATION EXPERIMENTS IN NORTHERN SAN DIEGO COUNTY, 1925 AND 1926

Farm	Location	Crop	Soil type	Average soil depth *feet*	Apparent specific gravity *per cent*	Average moisture equivalent	Source of water supply	Method of irrigation	Method of water measurement on plots
Whetstone	Vista	Lemons	Aiken loam	4.0–5.0	1.56	18.0	Vista Irrigation District	Furrow	Volumetric
Clemens	Fallbrook	Lemons	Sierra sandy loam	4.0–5.0	1.43	10.5	Pumping	Sprinkling	Volumetric
Marsh-Cruickshank	Vista	Lemons	Sierra sandy loam	2.5–4.5	1.53	12.6	Vista Irrigation District	Furrow	Volumetric
Hinrichs	Escondido	Oranges	Sierra sandy loam	2.5–5.0	1.54	13.7	Escondido Mutual Water Co	Furrow	Volumetric
Greaves	Escondido	Oranges	Holland sandy loam	4.0–5.0	1.57	13.5	Escondido Mutual Water Co	Sprinkling	Volumetric
Bowman	Vista	Lemons	Holland sandy loam	3.5–4.5	1.50	15.1	Vista Irrigation District	Furrow	Volumetric
Red Mountain	Fallbrook	Oranges	Holland sandy loam	5.0–6.0	1.55	13.0	Pumping	Sprinkling	Volumetric
McCormac	Fallbrook	Avocados	Sierra sandy loam	4.0–5.0	1.36	13.0	Pumping	Sprinkling and furrow	Volumetric
Wilson	Escondido	Lemons	Sierra sandy loam	2.5	1.52		Escondido Mutual Water Co	Furrow	Volumetric

USE OF WATER BY CITRUS AND AVOCADO TREES, OCTOBER, 1925, TO OCTOBER, 1926

During the winter 1925–1926, eight experimental plots were selected for study. A thorough soil sampling of each plot was made on October 15, a second on January 15, and a final one on April 1, just prior to the heavy rainfall of April 2 to 8 of that year. In order to make allowance for evaporation losses, rainfall of less than 0.5 inch was not considered in the final computation of winter use. This figure was obtained by observing the depth of moisture penetration after each rain and observing the rapidity of loss by evaporation from the wet soil surface.

Table 4 shows the main physical features of each of these experimental plots.

Tables 5 to 21, inclusive, show the average moisture content at each sampling, the dates and quantities of water applied at each irrigation, the calculated use of water, and the total seasonal requirement for the period from October, 1925, to October, 1926.

TABLE 5

Average Moisture Content and Dates and Amount of Irrigation, Whetstone Plot (Eureka Lemons), Vista, California, October 12, 1925, to October 13, 1926

Dates of sampling	Average moisture content of the soil, per cent					Dates of irrigation	Amount of irrigation water applied, acre-inches per acre
	First foot	Second foot	Third foot	Fourth foot	Fifth foot		
	Whole plot						
1925							
October 12	14.1	14.1	14.8	15.1	13.0		
1926							
January 9	7.1	9.9	12.6	12.6	12.1	January 9	0.90
March 22	9.0	12.7	13.3	13.3	14.4		
April 24	14.5	16.1	17.1	17.1	17.1		
May 24	11.0	14.9	16.7	17.5	16.7		
June 25	9.2	13.7	15.6	16.9	15.9		
	Irrigated section						
July 2	15.6	14.5	17.2	17.9		June 25, '29	0.84
August 2	8.6	11.5	14.8	16.6			
August 31	7.5	11.5	14.1	16.2		August 31	2.50
September 8	14.7	13.2	15.1	17.1			
October 13	7.9	11.4	14.2	15.8			
	Unirrigated section						
June 25	9.0	13.7	14.5	15.9	15.8		
October 5	6.2	9.8	12.4	14.4	14.1		

TABLE 6

COMPUTED SEASONAL USE OF WATER, WHETSTONE PLOT (EUREKA LEMONS), VISTA, CALIFORNIA, OCTOBER 15, 1925, TO OCTOBER 15, 1926

Winter use of water by trees and cover crop					Summer use of water by trees			
Dates	Number of days	Effective rainfall plus irrigation, inches	Soil-moisture loss or gain, acre-inches per acre*	Total use, acre-inches per acre	Dates	Number of days	Soil moisture loss, acre-inches per acre	Equivalent loss in 30 days, acre-inches per acre
Oct. 15 to Jan. 9	86	1.32	−2.85	4.17	Apr. 1 to May 24	54	1.84	1.02
Oct. 15 to Jan. 15	92			4.46†	May 25 to June 25	32	1.05	0.98
Jan. 10 to Mar. 22	72	5.51	+1.57	3.94	June 26 to July 31	36	1.82	1.51
Jan. 16 to Mar. 31	75			4.11†	Aug. 1 to Aug. 31	31	0.52	0.50‡
Oct. 15 to Mar. 31	167			**8.57**†	Sept. 1 to Oct. 15	45	1.85	1.23
					Apr. 1 to Oct. 15	198	**7.08**	

* Minus (−) sign indicates soil-moisture loss during interval. Plus (+) sign indicates soil-moisture gain during interval.

† Values obtained by interpolation. ‡ Trees suffered from drought during this period.

TABLE 7

AVERAGE MOISTURE CONTENT AND DATES AND AMOUNT OF IRRIGATION, MARSH-CRUICKSHANK PLOT (EUREKA LEMONS), VISTA, CALIFORNIA, OCTOBER 12, 1925, TO OCTOBER 22, 1926

Dates of sampling	Average moisture content of the soil, per cent				Dates of irrigation	Amount of irrigation water applied, acre-inches per acre
	First foot	Second foot	Third foot	Fourth foot		
	Whole plot					
1925						
October 12	11.2	12.1	9.6	10.3		
1926						
January 15	4.2	4.8	5.4	5.8	February 9	1.25
March 25	8.8	9.4	9.3			
April 13	13.8	14.5	13.6			
May 20	10.2	12.4	12.1			
June 25	9.2	11.5	12.5		June 2–3	1.25
July 12	8.0	10.9	11.9			
	Irrigated section					
July 15	13.9	12.7	12.0		July 12–13	1.30
August 17	8.7	12.0			August 17–18	1.14
August 20	12.2	12.6				
September 10	7.8	10.7			Sept. 22–23	0.83
September 27	10.1	10.3				
October 22	6.4	8.6				
	Unirrigated section					
July 12	6.8	10.1	10.8			
October 2	4.7	7.4	7.8			

TABLE 8

Computed Seasonal Use of Water, Marsh-Cruickshank Plot (Eureka Lemons), Vista, California, October 15, 1925, to October 15, 1926

Winter use of water by trees and cover crop (grass and weeds)					Summer use of water by trees			
Dates	Number of days	Effective rainfall plus irrigation, inches	Soil moisture loss or gain, acre-inches per acre	Total use, acre-inches per acre	Dates	Number of days	Soil moisture loss, acre-inches per acre	Equivalent loss in 30 days, acre-inches per acre
Oct. 15 to Jan. 15	92	1.32	−4.05	5.37	April 1 to June 1	62	2.25	1.08
Jan. 16 to Mar. 25	69	5.86	+2.44	3.42	June 2 to July 12	41	1.04	0.76
Jan. 16 to Mar. 31	75			3.74*	July 13 to Aug. 17	36	1.07	0.89
Oct. 15 to Mar. 31	167			**9.11***	Aug. 18 to Sept. 22	36	1.32	1.10
					Sept. 23 to Oct. 15	23	0.72	0.94
					April 1 to Oct. 15	198	**6.40**	

* Values obtained by interpolation.

TABLE 9

Average Moisture Content and Dates and Amount of Irrigation, Clemens Plot (Eureka Lemons), Fallbrook, California, October 13, 1925, to October 4, 1926

Dates of sampling	Average moisture content of the soil, per cent					Dates of irrigation	Amount of irrigation water applied, acre-inches per acre
	First foot	Second foot	Third foot	Fourth foot	Fifth foot		
1925							
October 13	9.4	10.3	9.4	10.1	8.9	Nov. 12, 1925	1.29
1926							
January 8	4.8	8.1	10.4	9.2	8.4	Jan. 26, 1926	1.54
March 20	5.8	7.9	10.9	12.4	10.7		
April 28	8.8	11.0	12.4	12.5	12.2		
June 23	5.1	8.0	10.7	11.3	10.0	June 24	2.05
October 4	6.2	7.4	8.4	9.2		July 31	1.86

TABLE 10

Computed Winter Use of Water by Trees and Cover Crop (Purple Vetch), Clemens Plot (Eureka Lemons), Fallbrook, California, October 15, 1925, to March 31, 1926

Dates	Number of days	Effective rainfall plus irrigation, inches	Soil moisture loss or gain, acre-inches per acre	Total use, acre-inches per acre
October 13 to January 8	88	3.33*	−1.35	4.68
October 15 to January 15	92			4.90†
January 9 to March 20	71	6.80	+1.38	5.42
January 16 to March 31	75			5.73†
October 15 to March 31	167			**10.63†**

* Includes one rain of less than 0.5 inch. † Values obtained by interpolation.

TABLE 11

AVERAGE MOISTURE CONTENT AND DATES AND AMOUNT OF IRRIGATION, HINRICHS PLOT (VALENCIA ORANGES), ESCONDIDO, CALIFORNIA, OCTOBER 19, 1925, TO OCTOBER 28, 1926

Dates of sampling	Average moisture content of the soil, per cent				Dates of irrigation	Amount of irrigation water applied, acre-inches per acre
	First foot	Second foot	Third foot	Fourth foot		
	Whole plot					
1925						
October 19	10.3	13.5	13.6	12.9		
1926						
January 12	4.7	7.6	10.7	11.5	January 15	2.32
March 23	7.6	11.4	12.1	13.0		
April 24	12.0	14.1	14.1	13.5		
June 7	7.5	12.0	12.7	11.4	June 10–12	2.34
	Irrigated section					
June 14	13.3	15.0	14.4	12.2		
July 20	6.4	11.4	13.3	13.2	July 21–23	1.80
July 26	12.5	12.9	14.2	13.6		
September 2	5.8	10.0	13.4	11.9	September 2–4	2.01
September 8	11.8	13.7	14.8	13.9		
October 28	5.8	9.8	12.2	13.0		
	Unirrigated section					
June 14	8.4	12.9	12.8	12.8		
October 12	5.0	7.8	11.1	12.3		

TABLE 12

COMPUTED SEASONAL USE OF WATER, HINRICHS PLOT (VALENCIA ORANGES), ESCONDIDO, CALIFORNIA, OCTOBER 15, 1925, TO OCTOBER 15, 1926

Winter use of water by trees and cover crop (purple vetch)					Summer use of water by trees			
Dates	Number of days	Effective rainfall plus irrigation, inches	Soil moisture loss or gain, acre-inches per acre	Total use, acre-inches per acre	Dates	Number of days	Soil moisture loss, acre-inches per acre	Equivalent loss in 30 days, acre-inches per acre
Oct. 19 to Jan. 12	85	1.66	−3.21	4.87	April 1 to June 9	70	3.01	1.28
Oct. 15 to Jan. 15	92			5.26*	June 10 to July 20	41	1.61	1.20
Jan. 13 to Mar. 23	69	7.83	+2.03	5.80	July 21 to Sept. 1	43	1.63	1.14
Jan. 16 to Mar. 31	75			6.22*	Sept. 2 to Oct. 15	44	1.39	0.95
Oct. 15 to Mar. 31	167			**11.48***	April 1 to Oct. 15	198	**7.64**	

* Values obtained by interpolation.

TABLE 13

Average Moisture Content and Dates and Amount of Irrigation, Red Mountain Plots (Navel Oranges), Fallbrook, California, April 15 to October 9, 1926

Dates of sampling	Average moisture content of the soil, per cent					Dates of irrigation	Amount of irrigation water applied, acre-inches per acre
	First foot	Second foot	Third foot	Fourth foot	Fifth foot		
	Trees 30 years old						
April 15	13.8	13.9	14.9	14.3	14.1		
May 25	7.2	10.3	12.1	12.3	13.0		
June 23	6.6	9.0	10.6	12.0	12.6		
July 22	6.0	7.4	8.9	10.3	11.5	July 26–28	2.62
August 17	9.0	10.0	10.1	10.5			
October 9	5.9	6.6	7.6	8.9		October 9	3.40
	Trees 6 years old						
April 15	13.2	14.8	14.9	14.2	14.1		
May 25	7.8	11.6	13.1	13.7	12.0		
June 23	7.8	10.6	11.6	12.9	10.8		
July 22	6.5	9.7	11.3	11.2	9.9	July 26	2.62
August 17	9.3	11.8	12.6	12.2			
October 9	6.5	7.8	9.0	11.0		October 9	3.40

TABLE 14

Computed Seasonal Use of Water, Red Mountain Plots (Navel Oranges), Fallbrook, California, April 1 to October 15, 1926

Summer use of water by old trees, acre-inches per acre				Summer use of water by young trees, acre-inches per acre			
Dates	Number of days	Soil-moisture loss	Equivalent loss in 30 days	Dates	Number of days	Soil-moisture loss	Equivalent loss in 30 days
April 1 to June 23	84	4.21	1.50	April 1 to June 23	84	3.55	1.27
June 24 to July 26	33	1.39	1.26	June 24 to July 26	33	1.07	0.98
July 27 to Oct. 15	81	3.63	1.35	July 27 to Oct. 15	81	3.27	1.21
April 1 to Oct. 15	198	**9.23**		April 1 to Oct. 15	198	**7.89**	

TABLE 15

AVERAGE MOISTURE CONTENT AND DATES AND AMOUNT OF IRRIGATION, GREAVES PLOT (VALENCIA ORANGES), ESCONDIDO, CALIFORNIA, OCTOBER 19, 1925, TO OCTOBER 29, 1926

Dates of sampling	Average moisture content of the soil, per cent					Dates of irrigation	Amount of irrigation water applied, acre-inches per acre
	First foot	Second foot	Third foot	Fourth foot	Fifth foot		
1925							
October 19	12.5	13.9	13.7	13.2	11.6		
1926							
January 12	7.2	8.5	10.9	11.0	10.1	January 16	1.42
March 23	5.6	9.2	10.9	11.0	10.0		
April 14	12.8	12.3	11.1	12.3	11.2	May 26	1.07
						July 2	2.15
						August 20	1.48
October 29	9.1	9.2	9.5	10.7	11.0	September 20	2.36

TABLE 16

COMPUTED WINTER USE OF WATER BY TREES AND COVER CROP (PURPLE VETCH), GREAVES PLOT (NAVEL ORANGES), ESCONDIDO, CALIFORNIA, OCTOBER 15, 1925, TO APRIL 1, 1926

Dates	Number of days	Effective rainfall plus irrigation, inches	Soil moisture loss or gain, acre-inches per acre	Total use, acre-inches per acre
October 15 to January 12	89	1.66	−3.38	5.04
October 15 to January 15	92			5.21*
January 12 to March 31	79	6.93	−0.21	7.14
January 16 to March 31	75			6.77*
October 15 to March 31	167			**11.98***

* Values obtained by interpolation.

TABLE 17

AVERAGE MOISTURE CONTENT AND COMPUTED USE OF WATER BY TREES, WILSON PLOT (EUREKA LEMONS), ESCONDIDO, CALIFORNIA, AUGUST 11 TO OCTOBER 13, 1926

Dates of sampling	Average moisture content of the soil, per cent			Use of water by trees			
	First foot	Second foot	Third foot	Dates	Number of days	Soil moisture loss, acre-inches per acre	Equivalent loss in 30 days, acre-inches per acre
August 11	12.9	9.8	8.0	Aug. 11 to Aug. 23	13	1.10	2.54
August 24	6.5	6.3	5.8	Aug. 24 to Sept. 7	15	0.21	0.42*
September 8	5.9	6.1	5.5	Sept. 15 to Sept. 28	14	0.99	2.11
September 15	14.4	13.0	11.2	Sept. 29 to Oct. 15	17	0.66	1.16†
September 29	8.8	9.8	9.3				
October 13	7.0	7.3	7.3				

* Heavy deficiency in soil moisture during this period.

† Deficiency in soil moisture during last part of this period.

TABLE 18

AVERAGE MOISTURE CONTENT AND DATES AND AMOUNT OF IRRIGATION, McCORMAC PLOT (AVOCADOS), FALLBROOK, CALIFORNIA, OCTOBER 14, 1925, TO OCTOBER 6, 1926

Dates of sampling	Average moisture content of the soil, per cent				Dates of irrigation	Amount of irrigation water applied, acre-inches per acre
	First foot	Second foot	Third foot	Fourth foot		
1925						
October 14	12.2	9.2	7.5	7.5		
1926						
January 8	8.1	7.9	7.2	6.7	January 9	1.66
March 16	9.8	10.6	11.8	10.4	March 16	1.65
April 15	13.4	12.0	12.4	10.3		
May 13	9.1	9.5	10.0	8.8		
June 9	7.3	7.6	8.5	8.7	June 14	1.94
June 29	7.3	7.7	8.0	8.0	June 30	1.92
July 19	6.7	7.0	7.3	7.6	July 20	1.39
August 23	5.4	5.6	5.2	5.9	August 23–27	7.90
August 30	11.3	10.7	9.9	9.8		
September 13	9.5	9.4	8.9	8.6		
October 6	7.2	7.4	7.2	7.2	October 8–9	2.64

TABLE 19

COMPUTED SEASONAL USE OF WATER, McCORMAC PLOT (AVOCADOS), FALLBROOK, CALIFORNIA, OCTOBER 15, 1925, TO OCTOBER 15, 1926

Winter use of water by trees (no cover crop)					Summer use of water by trees			
Dates	Number of days	Effective rainfall plus irrigation, inches	Soil moisture loss or gain, acre-inches per acre	Total use, acre-inches per acre	Dates	Number of days	Soil moisture loss, acre-inches per acre	Equivalent loss in 30 days, acre-inches per acre
Oct. 14 to Jan. 8	87	1.72*	−1.26	2.98	April 1 to May 13	43	2.43	1.70
Oct. 15 to Jan. 15	92			3.18‡	May 14 to June 14	32	1.02	0.96†
Jan. 9 to Mar. 16	67	6.83	2.07	4.76	June 15 to June 29	15	0.96	1.92
Jan. 16 to Mar. 31	75			5.34‡	June 30 to July 19	20	1.16	1.74†
Oct. 15 to Mar. 31	167			8.52‡	July 20 to Aug. 23	35	1.62	1.39†
					Aug. 24 to Sept. 13	21	1.31	1.86
					Sept. 14 to Oct. 15	32	1.70	1.59
					April 1 to Oct. 15	198	10.20	

* Includes one rain of less than 0.5 inch.

† Deficiency in soil moisture during this period.

‡ Values obtained by interpolation.

TABLE 20

SUMMARY OF WINTER USE OF WATER BY TREES AND COVER CROPS, OCTOBER 15, 1925, TO APRIL 1, 1926

Farm	Crop	Cover crop	Use of water, acre-inches per acre		
			Oct. 15 to Jan. 15	Jan. 16 to April 1	Oct. 15 to April 1
Whetstone	Lemons	Purple vetch (medium)	4.46	4.11	8.57
Marsh-Cruickshank	Lemons	Weeds and grass (medium)	5.37	3.74	9.11
Clemens	Lemons	Purple vetch (medium)	4.95	5.73	10.68
Hinrichs	Oranges	Purple vetch (medium)	5.26	6.22	11.48
Greaves	Oranges	Purple vetch (heavy)	5.21	6.77	11.98
Red Mountain	Oranges	Weeds and grass (medium)		6.88	
McCormac	Avocados	None	3.18	3.34	8.52

TABLE 21

SUMMARY OF PROBABLE USE OF WATER AND ESTIMATED IRRIGATION REQUIREMENTS OF EIGHT TYPICAL SAN DIEGO COUNTY GROVES FROM APRIL 1 TO OCTOBER 15, 1926

Farm	Location	Crop	Age of trees, years	Relative size of trees, per cent*	Probable use of water for each 30 days, acre-inches per acre			Probable total use of water, April 1 to October 15, acre-inches per acre
					Apr. 1 to June 30	July 1 to Aug. 31	Sept. 1 to Oct. 15	
Wilson	Escondido	Lemons	20+	100	2.00	2.50	2.20	14.30
Whetstone	Vista	Lemons	11	67	1.00	1.50	1.25	7.90
Marsh-Cruickshank	Vista	Lemons	12	50	1.00	1.20	1.10	7.00
Clemens	Fallbrook	Lemons	10	60	1.10	1.30	1.20	7.70
Hinrichs	Escondido	Oranges	6	50	1.20	1 20	1.00	7.50
Red Mt. Plot *A*	Fallbrook	Oranges	30	90	2.00	2.25‡	2.00‡	13.50
Red Mt. Plot *B*	Fallbrook	Oranges	6	50	1.10	1.30‡	1.20	7.70
McCormac	Fallbrook	Avocados	10	80	1.80	2.00‡	1.75	12.00

Farm	Carried over from winter rainfall, inches	To be supplied by irrigation, acre-inches per acre	Seasonal irrigation requirement acre-inches per acre†	Required number of irrigations	Average quantity of water required at each irrigation, acre-inches per acre	Interval between irrigations, days	Estimated seasonal requirement at maturity, acre-inches per acre
Wilson	2.10	12.20	20.0	6	3.25	25 to 30	20
Whetstone	2.00	5.90	10.0	4	2.50	35	15
Marsh-Cruickshank	1.80	5.20	8.5	4	2.0	35	17
Clemens	2.00	5.70	9.5	3	3.25	40	16
Hinrichs	2.40	5.10	8.5	3	2.75	45	17
Red Mt. Plot *A*	3.50	10.00	16.5	3	5.50	45	18
Red Mt. Plot *B*	2.50	5.20	8.5	3	2.75	45	17
McCormac	3.00	9.00	15.0	3	5.00	45	19

* With reference to probable size at maturity. This is based on a comparison of the averages of the outside areas of the trees included in each plot.

† On basis of 60 per cent efficiency in irrigation. ‡ Estimated values.

Table 22 shows the apparent root development in the various soil types at depths to which soil samples were taken in the different groves.

TABLE 22

Apparent Root Development in Various Soil Depths as Determined from the Rate of Water Extraction

Farm	Crop	Soil type	Depth of soil, feet	Apparent root development,* in percent				
				First foot	Second foot	Third foot	F'rth foot	Fifth foot
Wilson	Lemons	Sierra sandy loam	3.0	53	29	18		
Whetstone	Lemons	Aiken loam	5.0	55	21	13	6	5
Marsh-Cruickshank	Lemons	Sierra sandy loam	3.0	60	24	16		
Hinrichs	Oranges	Sierra sandy loam	4.0	48	28	13	11	
Red Mt. Plot *A*	Oranges	Holland sandy loam	5.0	35	28	19	13	5
Red Mt. Plot *B*	Oranges	Holland sandy loam	4.0	50	30	16	4	
McCormac	Avocados	Sierra sandy loam	4.0	36	24	22	18	

* It is assumed that the rate of soil-moisture loss from the various soil depths is a measure of the root development at those depths. The intervals during which soil moisture was available at all times are the only ones considered in obtaining these values. As an example, in the Wilson plot, during the intervals of August 11 to 24, and September 15 to 29, the total soil moisture taken from the first, second, and third feet was 12.0, 6.7, and 4.1 per cent, indicating an apparent root activity of 53 per cent in the first foot, 29 per cent in the second foot, and 18 per cent in the third foot.

USE OF WATER BY CITRUS AND AVOCADO TREES, MARCH 15 TO OCTOBER 25, 1927

At the beginning of the season of 1927, it was decided to reduce the area of the plots and materially increase the number of samples. Each plot was confined to an area cornered by four adjacent trees of uniform size, located at points in the groves where the soil type and depth were as nearly uniform as possible, and situated where conditions were favorable for uniform applications of water.

Where the furrow method of irrigation was used and where only a portion of the soil mass was wet by irrigation, the permanent points of sampling were located as shown in figure 2. Where the whole soil mass was moistened, either by furrow irrigation or by sprinkling, holes 14, 20, 22, 25, and 28 were eliminated, leaving 25 holes from which average moisture percentages and losses might be determined.

The results obtained in 1926 also show that because of a shortage of water, the trees in each plot suffered from drought at some time during the season; hence the quantity of water used by the trees depended upon the quantity of water available, and was not a true measure of what the use would have been had water been available in the soil at all times.

The plots selected for study in 1927 were so located that, in so far as possible, soil-moisture deficiencies would be avoided throughout the season.

The following is a brief description of each grove, with tables and diagrams showing the results obtained:

Tables 23 to 38 summarize the results of soil sampling and the computations of the quantities of water used in the intervals between irrigations. Figures 4 to 15 inclusive show, by means of diagrams, the seasonal variation in moisture content and the seasonal consumptive use of water in acre-inches per acre for each month during the irrigation season. A final summary of the use of water by months and the estimated irrigation requirements for each grove is contained in tables 39 and 41.

Wilkins Plot (Eureka Lemons), Escondido, Season of 1927.—This grove is located 2.5 miles east of Escondido, and contains 4.85 acres of mature trees. The trees are fully developed, the grove is well cared for, and the use of water should represent the requirement of a mature grove in this locality.

The soil is classed as a Sierra sandy loam, ranging in depth from 2.5 to 5 feet. Irrigation water is obtained from the Escondido Mutual Water Company, being distributed through a concrete pipe line and measured by means of a weir. The trees are planted on the square with a spacing of 24 feet. Furrow irrigation is used with 5 furrows spaced 3.5 feet apart, the outer furrows being 5 feet from the tree row.

At the time of the first sampling (March 15), determinations of apparent specific gravity were made by the soil-tube method. Samples were also taken at this time from which moisture-equivalent values were determined. These gave the following results:

DEPTH OF SOIL

	First foot	Second foot	Third foot	Fourth foot	Average
Apparent specific gravity	1.52	1.45	1.58	1.68	1.56
Moisture equivalent, per cent	9.9	9.9	11.3	13.1	11.0

TABLE 23

Results of Soil Sampling and Irrigation Data, Wilkins Plot (Eureka Lemons), Escondido, California, Season of 1927

Dates of sampling	Average moisture content of the soil, per cent				Dates of irrigation	Amount of irrigation water applied, acre-inches per acre	Per cent of soil mass moistened
	First foot	Second foot	Third foot	Fourth foot			
March 15	12.9	13.3	13.3	14.1			
April 6	11.7	11.1	12.3	13.9			
April 19	11.3	10.5	11.9	13.3			
May 11	9.5	9.1	10.5	12.7			
May 31	7.2	7.5	9.3	12.0			
June 9	6.5	6.8	8.9	11.7	June 9 and 10	6.40	90
June 21	11.1	12.1	12.8	13.9			
July 7	8.6	9.5	11.1	13.3			
July 22	6.9	7.3	9.1	12.4	July 24 to 27	6.40	100
August 5	11.5	12.2	13.0	13.8			
August 30	7.3	7.9	9.6	12.6			
September 10	6.0	6.4	9.0	12.2	Sept. 11 to 14	6.80	100
September 22	12.0	12.7	13.1	14.1			
September 30	10.7	11.5	12.7	13.9			
October 11	8.7	9.1	11.2	13.0			
October 19	8.0	8.3	10.6	12.9			
October 25	6.9	7.6	9.9	12.2			

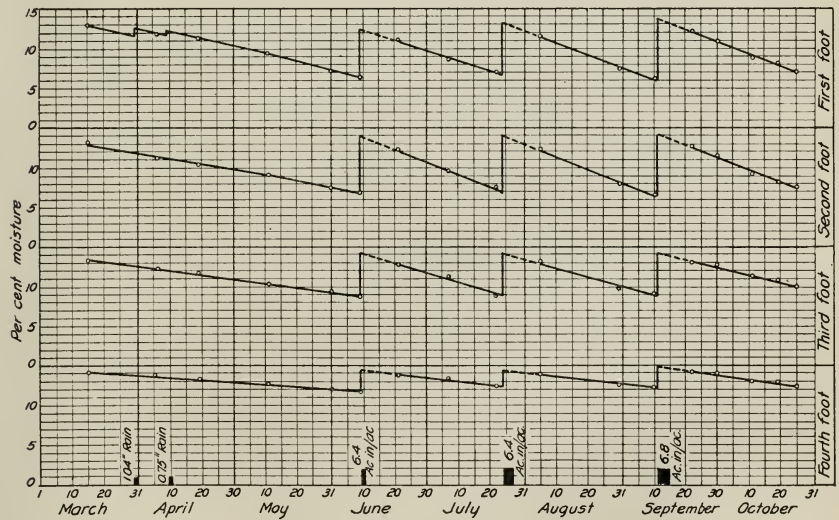


Fig. 4.—Seasonal variation in moisture content, Wilkins plot, season of 1927.

TABLE 24

QUANTITIES OF WATER USED IN INTERVALS BETWEEN IRRIGATIONS, WILKINS PLOT, SEASON OF 1927

Interval	Number of days	Soil-moisture loss, acre-inches per acre					
		First foot	Second foot	Third foot	Fourth foot	Total	Equivalent loss in 30 days
March 15–May 11	57	0.93	0.66	0.57	0.36	2.52	1.33
May 11–June 9	29	0.55	0.40	0.29	0.18	1.42	1.47
June 9–July 24	45	1.00	1.14	0.93	0.42	3.49	2.33
July 24–Sept. 11	49	1.37	1.37	1.03	0.45	4.22	2.58
Sept. 11–Oct. 25	44	1.23	1.17	0.83	0.52	3.75	2.55
March 15–Oct. 25	224	5.08	4.74	3.65	1.93	15.40	

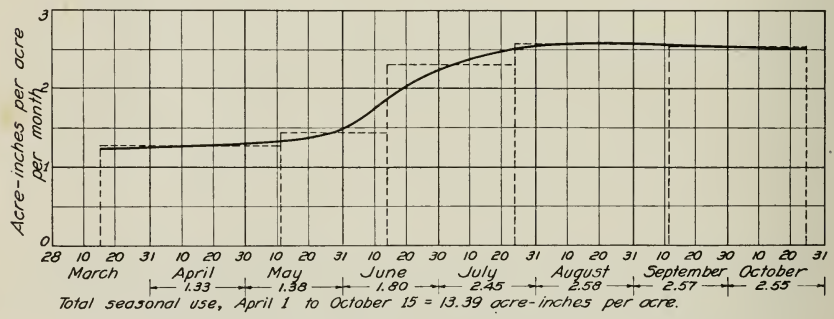


Fig. 5.—Seasonal use of water in acre-inches per acre per month, Wilkins plot, season of 1927.

An inspection of figure 4 shows that the field capacity of this soil is very close to 14 per cent, and that the moisture content of the top 2 feet of soil can be reduced to 7 per cent without an apparent change in the rate of use of water. Furthermore, the trees showed no evidence of lack of moisture throughout the season. If this is correct, at least 1.25 acre-inches per acre is available in each foot of the top 2 feet of soil. By the time this available moisture in the top 2 feet of soil has been used, 1.00 acre-inch per acre will have been taken from the third foot, and 0.50 acre-inch per acre from the fourth foot. Hence the total available supply is approximately 4 acre-inches per acre. With a total seasonal water requirement from April 1 to October 15 of 13.4 acre-inches per acre (fig. 5) 9.4 acre-inches per acre would have to be supplied by irrigation. On a basis of 60 per cent efficiency this would require that 16.0 acre-inches per acre of irrigation water be available to carry the grove to October 15.

If we assume that winter rainfall had been sufficient to leave the soil at field capacity on April 1, the first irrigation would be needed about June 20. With an average monthly use of 2.50 acre-inches per acre for the remainder of the summer, the maximum period between irrigations would be 45 to 50 days, the 45-day period probably being necessary under the rotation system of delivery.

The average use of water during the 45-day period would be 3.75 acre-inches per acre; and in order to supply this, 6.25 acre-inches per acre would have to be applied at each of the summer irrigations. Three such irrigations would carry the grove well into the month of November.

Clemens Plot (Eureka Lemons), Fallbrook, Season of 1927.— Because of the lack of uniformity of soil in the experimental plot in this grove in 1926, a new plot was selected equivalent in area to that occupied by a single tree.

At the beginning of the season, two single-tree plots were selected, on one of which a heavy cover crop of vetch was growing, the other being kept clean by cultivation. During the spring the first of these plots was used in determining the use of water by cover crops, the second plot being used in determining the summer use under clean cultivation. Water was obtained by pumping from a dug well, distribution being made through portable sprinklers. Throughout the season, the sprinklers were set directly under the trees, except during the irrigation of July 11 to 14, when an extra setting of the sprinklers was made in the center of the area between tree rows.

At the beginning of the season the following determinations of the moisture equivalent[8] and apparent specific gravity were made:

Depth of Soil

	First foot	Second foot	Third foot	Fourth foot
Plot 1, cover-cropped:				
Apparent specific gravity	1.45	1.43	1.55	1.58
Average moisture equivalent, per cent	7.3	8.6	9.9	10.9
Plot 2, clean cultivated:				
Apparent specific gravity	1.46	1.42	1.47	1.48

[8] The moisture equivalent was not determined for plot 2.

TABLE 25

RESULTS OF SOIL SAMPLING AND IRRIGATION DATA, CLEMENS PLOT (EUREKA LEMONS), FALLBROOK, CALIFORNIA, SEASON OF 1927

Dates of sampling	Average moisture content of the soil, per cent				Dates of irrigation	Amount of irrigation water applied, acre-inches per acre	Per cent of soil mass moistened
	First foot	Second foot	Third foot	Fourth foot			
PLOT 1 (cover-cropped)							
March 19	10.1	11.4	11.6	11.9			
March 25	7.9	10.5	10.9	11.7			
April 4	9.2	9.7	10.3	10.4			
April 18	8.5	9.3	9.6	10.3			
May 9	7.4	8.6	9.4	10.0			
June 2	6.4	7.4	8.9	9.6			
PLOT 2 (clean cultivated)							
June 10	7.4	7.7	9.9	11.1	June 6	2.31	
June 28	6.2	7.8	9.3	10.6			
July 19	9.0	9.5	10.1	11.0	July 11 to 14	4.64	100
August 2	6.8	8.5	9.5	10.9			
August 12	5.6	7.8	9.2	10.7	August 13	2.31	
August 19	7.3	8.5	9.6	11.1			
September 9	5.2	6.8	8.8	9.8			
September 26	4.5	6.2	8.1	9.9	September 29	1.93	13.5
October 5	6.2	6.5	8.7	10.2			
October 15	5.8	6.0	7.9	9.8			
October 21	5.9	6.1	8.0	9.7			

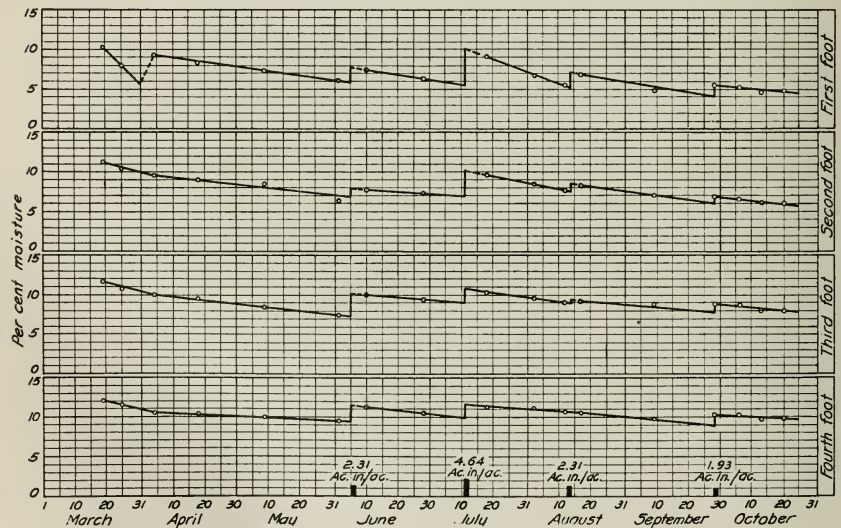


Fig. 6.—Seasonal variation in moisture content, Clemens plot, season of 1927.

TABLE 26

Quantities of Water Used in Intervals Between Irrigations, Clemens Plot, Season of 1927

Interval	Number of days	Soil-moisture loss, acre-inches per acre					
		First foot	Second foot	Third foot	Fourth foot	Total	Equivalent loss in 30 days
March 19–April 4	16	0.16	0.25	0.23	0.31	1.69*	3.19†
April 4–June 6	63	0.54	0.40	0.28	0.15	1.37	0.65
June 10–June 28	18	0.23	0.16	0.10	0.07	0.57	0.95
July 11–August 13	33	0.83	0.40	0.23	0.10	1.56	1.42
Aug. 13–Sept. 29	47	0.72	0.57	0.34	0.07	1.70	1.09
Sept. 29–Oct. 25	26	0.21	0.19	0.15	0.15	0.70	0.80

* Includes 0.74 inch rainfall. † Heavy loss because of cover crop.

During the summer, this grove received only one irrigation in which the whole soil surface was covered. With the exception of the one period between July 11 and August 13, which shows an average rate of use of 1.42 acre-inches per acre per 30 days, the rates shown in table 30 are not representative of what they would have been if sufficient moisture had been available to meet the demands of the trees throughout the season. If an average of two-thirds of the soil mass was moistened in the irrigations between June 13 and October 6, the average monthly use would be 0.96 acre-inch per acre. With 53 per cent of the root activity in the top foot of the soil, the interval between irrigations should be 40 days, and on a basis of moistening two-thirds of the soil mass, and with an efficiency of irrigation of 60 per cent, 2.0 acre-inches of water per acre is required at each irrigation. Four irrigations are thus needed to meet the seasonal requirement of 8.0 acre-inches per acre. With 100 per cent of the soil mass irrigated at each application, four irrigations of 3.0 acre-inches per acre each, totaling 12.0 acre inches per acre, would be necessary.

Treat Plot (Eureka Lemons), Vista, Season of 1927.—This property is located on the main highway one-half mile west of Vista. The soil is typical Sierra sandy loam, ranging in depth from 2.5 feet at the higher elevations to 4.0 feet on the lower portions.

The grove, containing 2.84 acres of mixed avocados and lemons, is 13 years old; but because of water shortage prior to 1926, the trees had not attained normal size for their age. The trees are planted on the contour, with an average spacing of 22.5 feet between tree rows. The furrow method of irrigation is used, with four furrows rather closely spaced in the center of the area between the rows. This spacing did not permit the moistening of more than 50 per cent of the soil mass occupied by the roots of the trees, and at each irrigation

two extra furrows were placed 5 feet from the tree row through the experimental plot.

Irrigation water was obtained from the Vista Irrigation District and was available on the growers' request.

The following determinations of the moisture equivalent and apparent specific gravity were made at the beginning of the season:

DEPTH OF SOIL

	First foot	Second foot	Third foot
Apparent specific gravity	1.44	1.43	1.47
Moisture equivalent, per cent	10.9	11.4	7.4

TABLE 27

RESULTS OF SOIL SAMPLING AND IRRIGATION DATA, TREAT PLOT (EUREKA LEMONS), VISTA, CALIFORNIA, SEASON OF 1927

Dates of sampling	Average moisture content of the soil, per cent			Dates of irrigation	Amount of irrigation water applied, acre-inches per acre	Per cent of soil mass moistened
	First foot	Second foot	Third foot			
	Irrigated section					
April 5	10.6	12.0	12.8			
April 20	9.5	11.2	12.4			
May 9	13.7	12.2	12.9	May 5 to 6	1.68	40
May 16	11.8	11.9	12.4			
June 6	8.1	10.4	11.3			
June 13	7.8	10.6	11.3	June 13	1.93	70
June 20	12.1	12.4	11.8			
July 5	9.1	11.2	11.8	July 14 to 16	3.27	69
July 23	11.2	12.0	12.4			
Aug. 1	8.8	11.6	12.1			
Aug. 13	7.0	9.5	9.9	August 15	2.34	69
Aug. 23	9.7	9.7	9.9			
Sept. 7	7.5	9.2	9.0			
Sept. 13	6.6	8.3	8.6	Sept. 13	2.17	65
Sept. 21	10.5	10.7	11.9			
Sept. 28	9.2	10.0	10.2			
Oct. 6	8.1	9.3	9.7			
Oct. 14	7.4	8.9	10.2			
Oct. 17	7.0	8.4	8.4			
Oct. 20	6.8	8.6	8.7			
Oct. 24	6.6	8.2	8.2			
	Unirrigated section					
May 9	8.8	11.0	12.0			
May 16	8.5	11.1	12.4			
June 6	7.8	10.2	11.4			
June 13	6.7	9.8	10.8			
June 20	6.6	9.8	11.6			
July 5	6.7	9.5	11.3			
July 23	6.3	9.2	10.6			
Aug. 13	5.6	8.7	10.0			
Aug. 23	5.1	8.4	9.6			
Sept. 13	5.1	7.8	8.8			
Sept. 21	4.9	7.1	8.6			
Oct. 7	5.1	7.7	8.6			
Oct. 17	5.2	7.2	8.5			

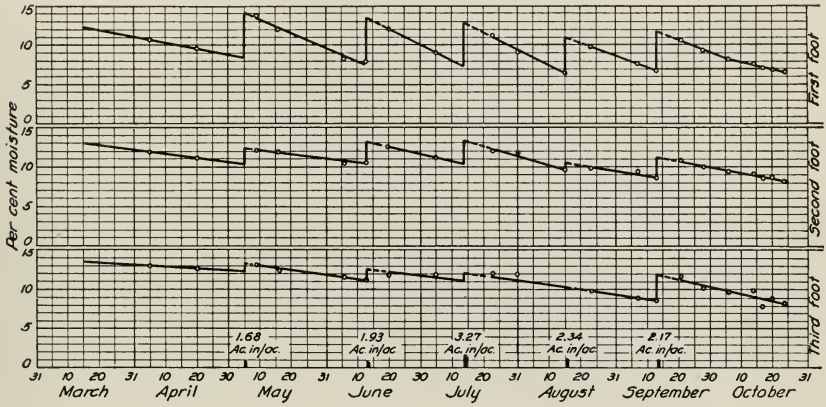


Fig. 7A.—Seasonal variation in moisture content of irrigated section, Treat lemon plot, season of 1927.

Dotted portions of lines represent the assumed moisture condition between irrigation and subsequent sampling.

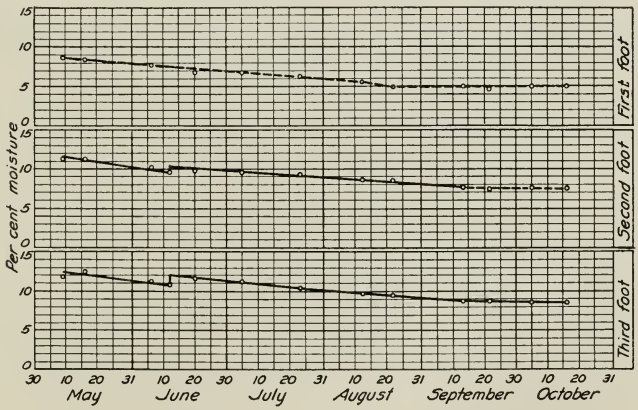


Fig. 7B.—Seasonal variation in moisture content of unirrigated section, Treat lemon plot, season of 1927.

TABLE 28

QUANTITIES OF WATER USED FROM IRRIGATED AND UNIRRIGATED SOIL SECTIONS IN INTERVALS BETWEEN IRRIGATIONS, TREAT PLOT, SEASON OF 1927

Interval	Number of days	Irrigated soil section, soil-moisture loss, acre-inches per acre			Unirrigated soil section, soil-moisture loss, acre-inches per acre			Total acre-inches per acre	Equivalent loss in 30 days, acre-inches per acre
		First foot	Second foot	Third* foot	First foot	Second foot	Third† foot		
April 1–May 5	35	0.42	0.33	0.06				0.81	0.70
May 5–June 13	39	0.46	0.15	0.03	0.22	0.11	0.09	1.06	0.81
June 13–July 14	31	0.74	0.31	0.04	0.04	0.05	0.03	1.21	1.17
July 14–Aug. 15	32	0.75	0.42	0.04	0.04	0.05	0.04	1.34	1.25
Aug. 15–Sept. 13	29	0.51	0.21	0.05	0.02	0.05	0.03	0.87	0.90
Sept. 13–Oct. 25	42	0.70	0.33	0.10				1.13	0.81

* 2.0 to 2.33 feet. † 2.0 to 2.77 feet.

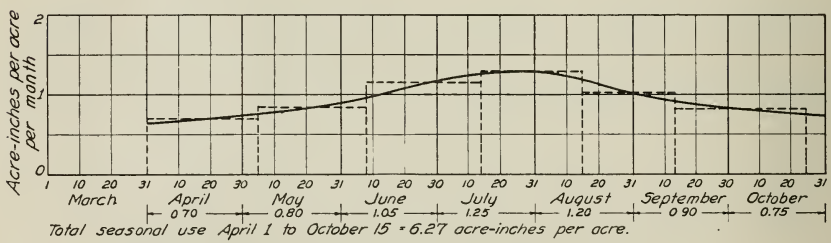


Fig. 8.—Seasonal use of water in acre-inches per acre per month, Treat lemon plot, season of 1927.

For this grove, figure 8 shows the total seasonal use from April 1 to October 13 to be 6.3 acre-inches per acre, with a maximum monthly requirement of 1.25 acre-inches per acre during July and August. The soil moisture curves in figures 7A and 7B show this soil to have a field capacity of 12 per cent and a wilting point of 6 per cent. With an average depth of soil of 2.5 feet, and with 63 per cent of the root activity in the top foot of soil, 1.65 acre-inches per acre would be available in the soil in the periods between irrigations. With a maximum rate of use of 1.25 acre-inches per acre per month during July and August, the proper interval between irrigations during the period would be 35 days. This interval could be extended to 45 days during the spring and to 40 days in the fall. With two-thirds of the soil mass moistened, and on a basis of 60 per cent efficiency in irrigation, four irrigations averaging 2.0 acre-inches per acre would be needed, giving a total seasonal requirement of 8.0 acre-inches per acre. Assuming that this

grove is 76 per cent grown, the water requirement at maturity under the present practice of moistening two-thirds of the soil mass would be 10.5 acre-inches per acre.

At maturity and with 100 per cent of the soil mass moistened at each irrigation, the seasonal irrigation requirement would be 16 acre-inches per acre.

Hinrichs Plots (Valencia Oranges), Escondido, Season of 1927.— During 1927, soil sampling and measurement of irrigation water were continued in this grove, the experimental plots being moved to a more favorable location having a more uniform soil type than that found in the 1926 plots. The grove is irrigated by the furrow method, a set of three furrows 21 inches apart being placed on each side of each tree row for the June irrigation, and a similar set 3 feet apart for the July and September irrigations. An average of 64 per cent of the soil mass was moistened at each irrigation. The favorable location of the plot and the uniformity of the soil afforded an excellent opportunity for accurate determination of the efficiency of irrigation and the percentage of the soil mass moistened at each irrigation, as well as a measure of soil-moisture loss from irrigated and unirrigated soil sections. Figure 2 shows the location of furrows and points of soil sampling in this grove during 1927.

Beginning with the first irrigation on June 8 a second plot (*B*) was located, in which 90 per cent of the soil mass was moistened at each irrigation. This offered an opportunity to compare the rate of loss when different percentages of the soil mass were irrigated.

The following apparent specific gravity and moisture equivalent determinations were made on plot *A* at the beginning of the season:

Depth of Soil

	First foot	Second foot	Third foot	Fourth foot
Apparent specific gravity	1.49	1.52	1.54	1.58
Moisture equivalent, per cent	11.3	14.1	14.8	14.5

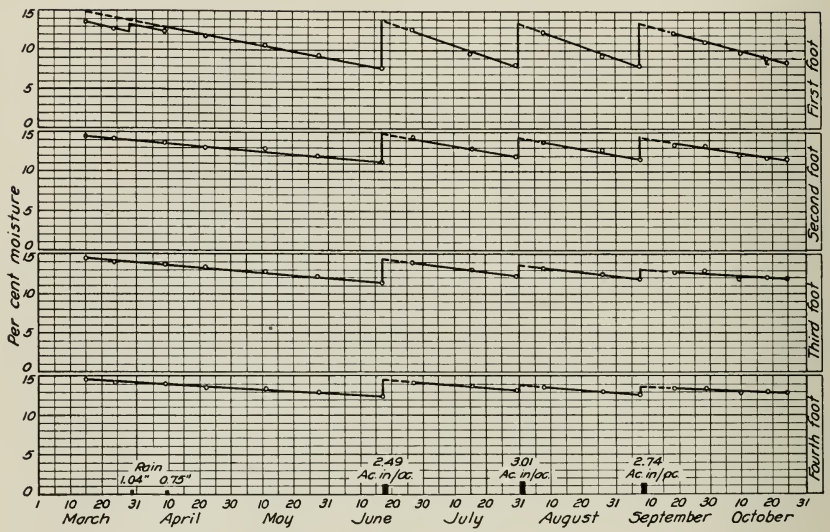


Fig. 9A.—Seasonal variation in moisture content of irrigated section, Hinrichs grove (plot *A*), season of 1927.

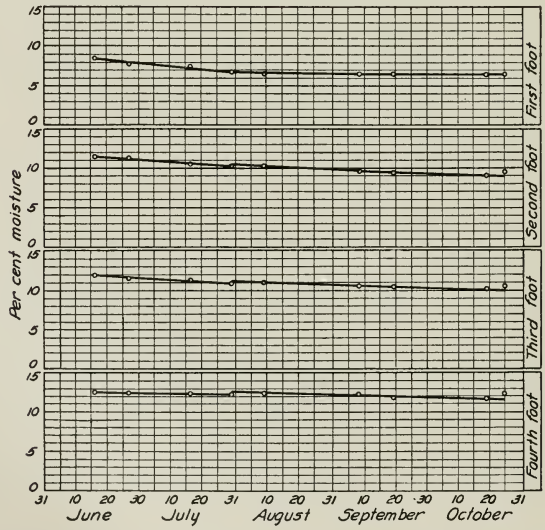


Fig. 9B.—Seasonal variation in moisture content of unirrigated section, Hinrichs grove (plot *A*), season of 1927.

TABLE 29

Results of Soil Sampling and Irrigation Data, Hinrichs Grove (Plot *A*, Valencia Oranges), Escondido, California, Season of 1927

Dates of sampling	Average moisture content of the soil, per cent				Dates of irrigation	Amount of irrigation water applied, acre-inches per acre	Per cent of soil mass moistened
	First foot	Second foot	Third foot	Fourth foot			
	Whole plot						
Mar. 16	13.5	14.6	14.4	14.8			
Mar. 24	12.6	14.2	13.9	14.2			
April 9	12.4	13.7	13.6	14.0			
April 22	11.8	13.1	13.1	13.5			
May 11	10.9	12.6	12.7	13.4			
May 28	9.4	12.0	12.1	12.9			
June 17	7.7	11.0	11.5	12.3		2.49	62
	Irrigated section						
June 27	12.9	14.2	13.9	14.3	June 17–19		
July 16	9.6	12.6	12.8	13.7			
July 30	8.2	11.8	12.2	13.2	July 30	3.01	64
Aug. 8	12.4	13.5	13.1	13.6			
Aug. 27	9.2	12.6	12.6	13.0			
Sept. 8	8.2	11.4	11.7	12.5	Sept. 8	2.74	67
Sept. 19	12.3	13.3	12.7	13.4			
Sept. 29	11.0	13.2	13.0	13.6			
Oct. 10	9.6	12.2	11.7	12.7			
Oct. 19	9.1	11.6	11.9	12.7			
Oct. 25	8.5	11.5	11.8	12.9			
	Unirrigated section						
June 27	7.8	11.3	11.6	12.4			
July 16	7.4	10.6	11.2	12.3			
July 30	6.8	10.2	10.9	12.0			
Aug. 8	6.6	10.0	11.0	12.3			
Sept. 8	6.6	9.7	10.8	12.2			
Sept. 19	6.4	9.4	10.3	11.6			
Oct. 19	6.2	8.9	10.0	11.8			
Oct. 25	6.4	9.5	10.5	12.2			

TABLE 30

QUANTITIES OF WATER USED FROM IRRIGATED AND UNIRRIGATED SOIL SECTIONS IN INTERVALS BETWEEN IRRIGATIONS, HINRICHS GROVE (PLOT *A*), SEASON OF 1927

Interval	Number of days	Irrigated soil section, soil-moisture loss, acre-inches per acre				Unirrigated soil section, soil-moisture loss, acre-inches per acre				Total acre-inches per acre	Equivalent loss in 30 days, acre-inches per acre
		1st foot	2nd foot	3rd foot	4th foot	1st foot	2nd foot	3rd foot	4th foot		
March 16–April 9	24	0.20	0.16	0.17	0.15					1.22*	1.59†
April 9–June 17	69	0.95	0.49	0.39	0.27					2.10	.0.91
June 17–July 31	44	0.67	0.34	0.26	0.17	0.12	0.09	0.07	0.04	1.76	1.20
July 31–Sept. 8	39	0.60	0.32	0.20	0.17	0.01	0.03	0.02	0.01	1.36	1.05
Sept. 8–Oct. 25	47	0.61	0.33	0.15	0.10	0.01	0.03	0.03	0.01	1.27	0.81

* Includes 0.53 inch rainfall. † Heavy loss due to cover crop.

An inspection of figures 9A and 9B shows that the field capacity of this soil is from 13.5 to 15 per cent and that the wilting point is probably about 7.0 per cent, the latter being indicated in figure 9B by the break in the moisture curve of the top foot of the unirrigated soil mass. With 47 per cent of the root system in the top foot of soil, which is figured from rate of soil moisture loss, irrigation water should be applied when the top foot reaches the wilting point. Under these conditions, and with the top 4 feet of soil at field capacity on April 1, about 2.5 acre-inches of water per acre would be available for use before irrigation was necessary. The soil-moisture curves shown in figure 9A indicate that this point would be reached on or shortly after June 20. During the irrigation season, with two-thirds of the soil mass moistened at each irrigation, 1.65 acre-inches per acre would be available, and at an average rate of use of 1.0 acre-inch per acre per month, the proper interval of irrigation would be 45 days. On a basis of 60 per cent efficiency in irrigation, 2.50 acre-inches per acre would be applied at each irrigation. Under the above conditions, three seasonal irrigations, totaling 7.50 acre-inches per acre, would be required. On a basis of two-thirds of the soil mass being moistened at each irrigation, this grove being assumed to be 40 per cent grown, the seasonal requirement at full growth would be 18 acre-inches per acre.

In connection with the soil-moisture diagram shown in figures 9A and 9B, there is no indication either in the irrigated or in the unirrigated soil sections that the rate of moisture extraction decreases as the moisture per cent decreases. This would indicate that as long as the moisture content of the soil is above the wilting point, the soil water is as readily available as when the moisture content is near or

at field capacity. It is further noted that when the moisture content of the unirrigated soil section reaches the wilting point, there is no apparent increase in the rate of moisture extraction from the irrigated soil zone.

TABLE 31

Results of Soil Sampling and Irrigation Data, Hinrichs Grove (Plot *B*, Valencia Oranges), Escondido, California, Season of 1927

Dates of sampling	Average moisture content of the soil, per cent			Dates of irrigation	Amount of irrigation water applied, acre-inches per acre	Per cent of soil mass moistened
	First foot	Second foot	Third foot*			
Mar. 15	12.0	12.2	12.5	June 8 to 9	2.49	90
June 8	5.2	7.6	9.6			
June 15	10.9	12.2	12.6			
July 20	5.0	8.1	11.1	July 20	3.01	90
July 30	9.6	12.2	13.0			
Sept. 1	5.5	8.6	11.0	Sept. 1	2.74	90
Sept. 12	10.8	12.8	13.5			
Sept. 29	7.8	10.5	11.7			
Oct. 24	5.4	8.2	10.1			

* 2.0 to 2.8 feet.

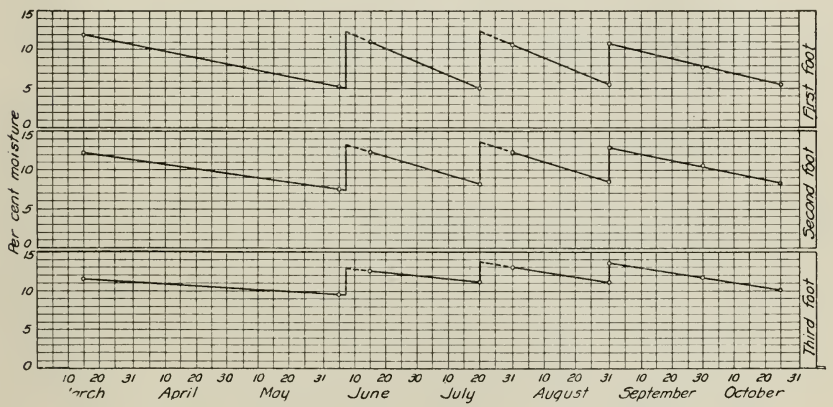


Fig. 10.—Seasonal variation in moisture content, Hinrichs grove (plot *B*), season of 1927.

TABLE 32

Quantities of Water Used in Intervals Between Irrigations, Hinrichs Grove (Plot *B*), Season of 1927

Interval	Number of days	Soil-moisture loss, acre-inches per acre				
		First foot	Second foot	Third foot	Total	Equivalent loss in 30 days
April 9–June 8	60	0.87	0.59	0.22	1.68	0.84
June 8–July 20	41	0.72	0.60	0.19	1.51	1.10
July 30–September 1	33	0.75	0.66	0.20	1.62	1.47
September 1–October 24	53	1.04	0.84	0.37	2.25	1.28

Figure 10 shows the field capacity and wilting point of the soil of plot *B*, averaging 2.58 feet in depth, to be approximately the same as that for plot *A*, which has an average depth of 4 feet.

During the interval from April 1 to June 15, plot *A* showed a loss of 2.34 acre-inches per acre and plot *B* a loss of 2.10 acre-inches per acre, with a loss for the remainder of the season of 4.51 acre-inches per acre from plot *A* and 5.18 acre-inches per acre from plot *B*. Considering the differences in use by the two plots between April 1 and June 15, and for the soil moisture loss from the unirrigated soil section of plot *A* from June 15 to October 15, the losses from the two plots are approximately in direct proportion to the average percentage of the soil mass moistened at each irrigation.

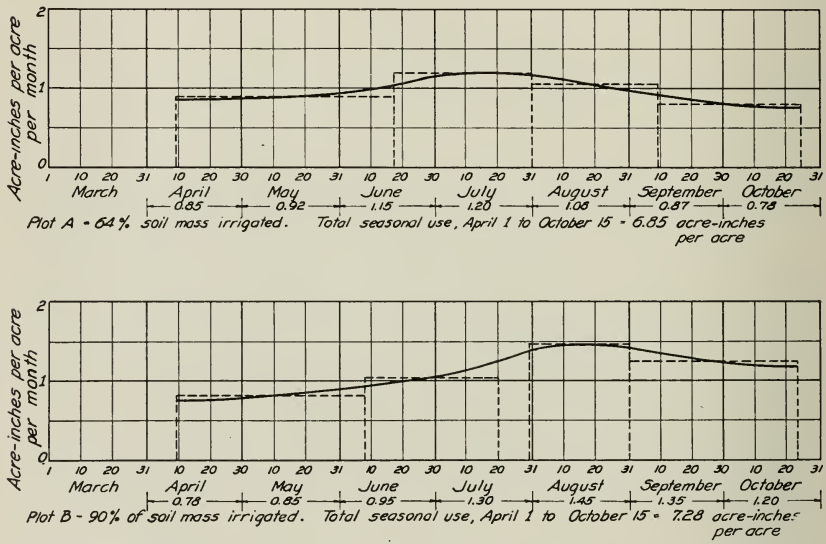


Fig. 11.—Seasonal use of water in acre-inches per acre per month, Hinrichs grove (plots *A* and *B*), season of 1927.

In plot *A*, July was the month of maximum use, while in plot *B* maximum use is shown in August. In plot *A*, during July there was still available moisture in the unirrigated soil zone, while during the remainder of the summer the monthly losses were a measure of the water available in the moistened zone. The total seasonal loss from plot *A* is a measure of the quantity of water available rather than a measure of the quantity which would have been used if a full moisture supply had been available throughout the season.

Plot *B*, with 90 per cent of the soil mass moistened, represents the probable water requirement of this grove with approximately a full

supply of moisture available throughout the summer. With this quantity of water applied, the period between irrigations would remain at 45 days and under 60 per cent efficiency, 3.5 acre-inches per acre should be applied at each irrigation.

Red Mountain Plots (Navel Oranges), Season of 1927.—The results obtained from this grove during 1926 yielded little information concerning the total seasonal water requirement of either the old or young trees. Throughout the season there was a deficiency in irrigation water applied; and, in consequence, the results obtained were a measure of the water available rather than of the water requirement.

In the continuation of the work of 1927, arrangements were made whereby irrigation water would be applied at the proper intervals and in proper quantities to keep an ample supply of moisture available to meet the needs of both young and old trees throughout the season.

The following determinations of the moisture equivalent and apparent specific gravity were made at the beginning of the irrigation season:

	Depth in Feet				
	First foot	Second foot	Third foot	Fourth foot	Fifth foot
Apparent specific gravity	1.45	1.33	1.45	1.63	1.73
Moisture equivalent, per cent	13.5	13.9	14.0	15.1	16.9

TABLE 33

Results of Soil Sampling and Irrigation Data, Red Mountain Grove (Plot *A*, 31-Year-Old Navel Oranges), Fallbrook, California, Season of 1927

Dates of sampling	Average moisture content of the soil, per cent					Dates of irrigation	Amount of irrigation water applied, acre-inches per acre	Per cent of soil mass moistened
	First foot	Second foot	Third foot	Fourth foot	Fifth foot			
Mar. 17	13.5	13.7	14.0	14.6	14.8			
April 8	11.8	12.7	13.4	13.8	14.6			
April 21	11.0	12.0	12.6	13.3	14.2			
May 10	9.6	11.3	12.3	13.0	14.2			
May 25	8.9	10.2	11.4	12.5	13.9			
June 3	8.4	9.7	10.8	12.2	13.7	June 4	4.28	100
June 11	11.9	11.8	11.8	12.6	13.8			
June 29	9.4	10.8	11.4	12.4	13.7			
July 15	8.1	9.4	10.3	11.6	13.5			
July 25	7.4	8.6	9.8	11.5	13.5	July 27	7.50	100
Aug. 6	11.7	13.0	13.5	13.8	13.9			
Aug. 24	9.2	11.5	12.5	12.8	13.7			
Sept. 5	8.4	9.9	11.3	12.3	13.9	Sept. 5	No information	
Sept. 15	11.2	11.6	12.2	12.8	14.2	Sept. 22	No information	
Oct. 1	12.1	12.8	13.7	14.0	14.5			
Oct. 13	10.3	12.2	12.8	12.9	14.0			
Oct. 21	9.2	11.1	12.5	13.5	14.4			
Oct. 26	9.0	11.1	12.1	12.8	14.0			

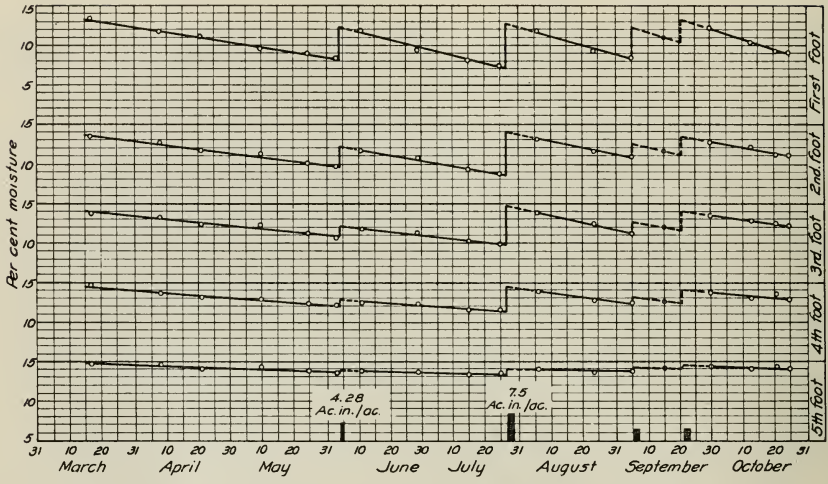


Fig. 12.—Seasonal variation in moisture content, Red Mountain grove (plot *A*), season of 1927.

TABLE 34

QUANTITIES OF WATER USED IN INTERVALS BETWEEN IRRIGATIONS, RED MOUNTAIN GROVE (PLOT *A*), SEASON OF 1927

Interval	Number of days	Soil-moisture loss, acre-inches per acre						
		First foot	Second foot	Third foot	Fourth foot	Fifth foot	Total	Equivalent loss in 30 days
March 15–June 4	81	0.87	0.65	0.55	0.48	0.24	2.79	1.03
June 4–July 27	53	0.89	0.61	0.42	0.31	0.11	2.34	1.32
July 27–September 5	40	0.79	0.53	0.60	0.48	0.05	2.45	1.84
October 1–October 25	24	0.55	0.29	0.25	0.18	0.07	1.34	1.68
November 9–December 8	29	0.58	0.36	0.29	0.21	.....	1.44	1.49

TABLE 35

RESULTS OF SOIL SAMPLING AND IRRIGATION DATA, RED MOUNTAIN GROVE (PLOT *B*, 7-YEAR-OLD NAVEL ORANGES), SEASON OF 1927

Dates of sampling	Average moisture content of the soil, per cent				Dates of irrigation	Amount of irrigation water applied, acre-inches per acre	Per cent of soil mass moistened
	First foot	Second foot	Third foot	Fourth foot			
Mar. 15	13.3	13.9	14.1	12.9			
June 4	9.0	10.6	10.9	10.5	June 4	2.50	100
June 13	11.8	12.2	11.8	10.2			
July 6	9.9	11.3	11.0	9.5			
July 29	8.3	10.2	10.1	9.3	July 29	5.00	100
Aug. 6	13.2	14.3	13.5	12.7			
Sept. 5	10.8	12.9	12.4	11.4			
Sept. 22	9.7	11.9	12.2	11.2	Sept. 22	5.00	100
Oct. 5	13.3	14.3	14.2	12.8			

TABLE 36

Quantities of Water Used in Intervals Between Irrigations, Red Mountain Grove (Plot *B*), Season of 1927

Interval	Number of days	Soil-moisture loss, acre-inches per acre					
		First foot	Second foot	Third foot	Fourth foot	Total	Equivalent loss in 30 days
March 15–June 4	81	0.75	0.52	0.55	0.41	2.23	0.83
June 13–July 29	46	0.61	0.30	0.30	0.23	1.44	0.94
August 6–Sept. 22	47	0.61	0.38	0.23	0.27	1.49	0.95

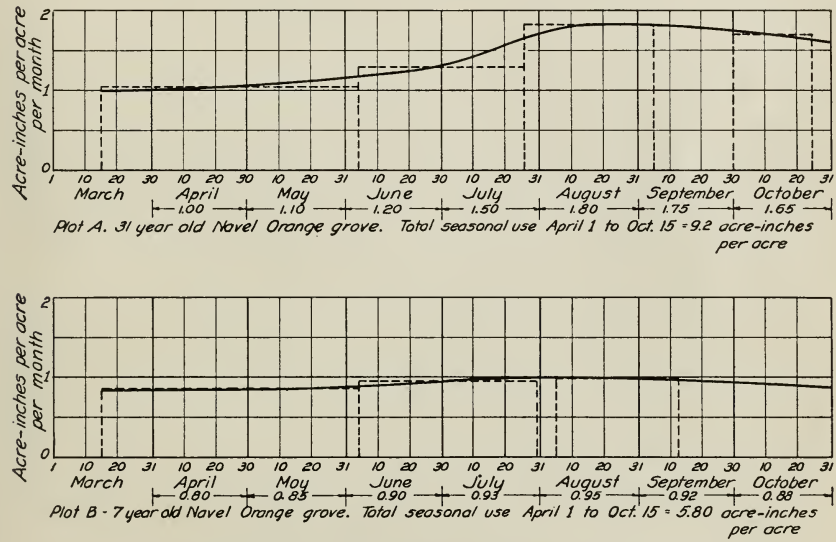


Fig. 13.—Seasonal use of water in acre-inches per acre per month, Red Mountain grove (plots *A* and *B*), season of 1927.

With the soil in plot *A* having a field capacity of 12.5 per cent and a wilting point of 7 per cent, there would be available 3.10 acre-inches of water per acre before the top 2 feet of soil would have reached the wilting point. With an average summer use by the trees of 1.70 acre-inches per acre per month, the correct interval between irrigations would be slightly over 50 days. Allowing for a reasonable margin of safety, good practice would call for a 45-day period between irrigations. During this period 2.55 acre-inches of water would have been used, and on a basis of 60 per cent efficiency and with 100 per cent of the soil mass moistened, a depth of 4.25 acre-inches per acre should be applied. Three irrigations would bring the total seasonal requirement of this grove to 12.75 acre-inches per acre.

In plot *B*, with the same soil type and the same water-holding capacity as found in plot *A*, there would be available 2.35 acre-inches per acre before the top foot of soil would reach the wilting point. With an average use of water during the summer of 0.90 acre-inch per acre, a 45-day interval between irrigations would provide ample water to meet the transpiration use of the grove. This use, with 100 per cent of the soil mass moistened and an efficiency of 60 per cent, would require a depth of application of 2.25 acre-inches per acre at each irrigation, with a total seasonal requirement of 6.75 acre-inches per acre for three irrigations. If we assume this grove to be 36 per cent grown, the water requirement at full growth would be 18.5 acre-inches per acre.

Treat Avocado Plot, Season of 1927.—At the beginning of the season of 1927, a new plot was chosen for study of use of water by avocados. This was located one-quarter mile west of Vista and contained 3½ acres of mixed varieties. The trees, which were 13 years old and of somewhat uneven size, were planted on the contour with an average spacing of 27 feet and were irrigated by the furrow method. The soil is decomposed granite (Sierra sandy loam), its average depth in the experimental plot being 2.5 feet.

In the main portion of the grove, two irrigation furrows spaced 2 feet apart were placed on each side of the tree row. After the first irrigation, in order to moisten a greater percentage of the soil mass, six furrows were used in the experimental plot, the inner furrows being about 6 feet from the tree row.

At the beginning of the season the following determinations of the moisture equivalent and apparent specific gravity were made:

DEPTH OF SOIL

	First foot	Second foot	Third foot
Apparent specific gravity	1.46	1.36	1.43
Moisture equivalent, per cent	10.3	10.1	8.4

TABLE 37

Results of Soil Sampling and Irrigation Data, Treat Plot (Avocados), Vista, California, Season of 1927

Dates of sampling	Average moisture content of the soil, per cent			Dates of irrigation	Amount of irrigation water applied, acre-inches per acre	Per cent of soil mass moistened
	First foot	Second foot	Third foot*			
	Irrigated section					
Mar. 12	12.5	12.8	10.8			
Mar. 26	10.3	11.2	10.7			
April 5	10.9	11.8	12.6			
April 20	9.6	11.0	11.9			
May 9	13.7	13.4	14.4	May 5 to 6	1.68	38
May 16	10.9	12.1	12.9			
June 6	7.8	9.9	10.3			
June 13	7.5	9.3	9.6	June 13 to 14	1.93	67
June 20	11.5	12.2	12.2			
July 5	8.3	10.1	11.3	July 14 to 16	3.27	66
July 23	10.1	11.1	10.5			
Aug. 1	7.8	9.2	9.7			
Aug. 13	6.5	7.8	8.1	Aug. 15 to 17	2.34	66
Aug. 23	9.9	9.8	8.1			
Sept. 7	7.0	7.7	8.0			
Sept. 13	6.0	7.2	6.8	Sept. 13 to 14	2.17	62
Sept. 21	10.8	10.8	8.7			
Sept. 28	8.8	9.0	9.0			
Oct. 6	7.5	8.2	7.5			
Oct. 17	6.2	7.5	7.1	Oct. 24 to 25	1.86	
Oct. 24	5.6	6.4	6.6			
	Unirrigated section					
May 9	9.2	10.5	11.0			
May 16	8.8	10.6	10.7			
June 6	7.0	8.6	9.0			
June 13	6.5	7.9	9.0			
June 20	6.2	7.8	9.7			
July 5	5.8	6.8	8.0			
July 23	5.7	6.9	8.0			
Aug. 13	5.0	6.2	6.4			
Aug. 23	4.5	5.6	6.4			
Sept. 13	4.5	5.8	6.1			
Oct. 17	4.7	5.8	6.3			

* 2.0 to 2.33 feet.

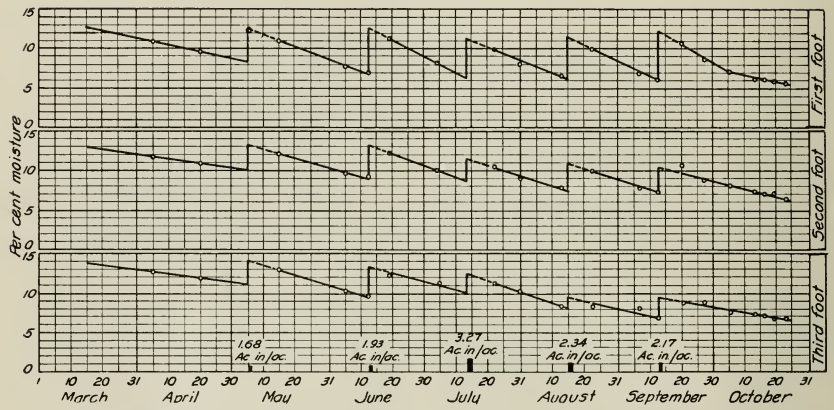


Fig. 14.—Seasonal variation in moisture content of irrigated section, Treat avocado plot, season of 1927.

TABLE 38

QUANTITIES OF WATER USED IN INTERVALS BETWEEN IRRIGATIONS, TREAT PLOT (AVOCADOS), SEASON OF 1927

Interval	Number of days	Irrigated soil section, soil-moisture loss, acre-inches per acre			Unirrigated soil section, soil-moisture loss, acre-inches per acre			Total acre-inches per acre	Equivalent loss in 30 days, acre-inches per acre
		First foot	Second foot	Third* foot	First foot	Second foot	Third† foot		
April 5–April 20	15	0.22	0.12	0.05	.....	.....	.....	0.39	0.79
May 5–June 13	39	0.37	0.26	0.10	0.26	0.18	0.13	1.30	1.00
June 13–July 14	31	0.78	0.48	0.14	0.06	0.07	0.05	1.58	1.53
July 14–Aug. 15	32	0.63	0.45	0.16	0.06	0.08	0.06	1.44	1.35
Aug. 15–Sept. 13	29	0.64	0.39	0.09	.....	.....	.....	1.12	1.15
Sept. 13–Oct. 6	23	0.50	0.24	0.04	.....	.....	.....	0.78	1.02
Oct. 6–Oct. 24	18	0.23	0.18	0.04	.....	.....	.....	0.45	0.76

* 2.0 to 2.33 feet.

† 2.0 to 2.68 feet.

The use-of-water curves shown in figure 15 indicate that there was a deficiency in soil moisture in the latter part of each of the periods between irrigations after midsummer. The probable use-of-water curve shows the quantity of water which would have been taken from the irrigated section if a full supply had been available during the entire period between irrigations; while the actual curve is a measure of the water which was available for use.

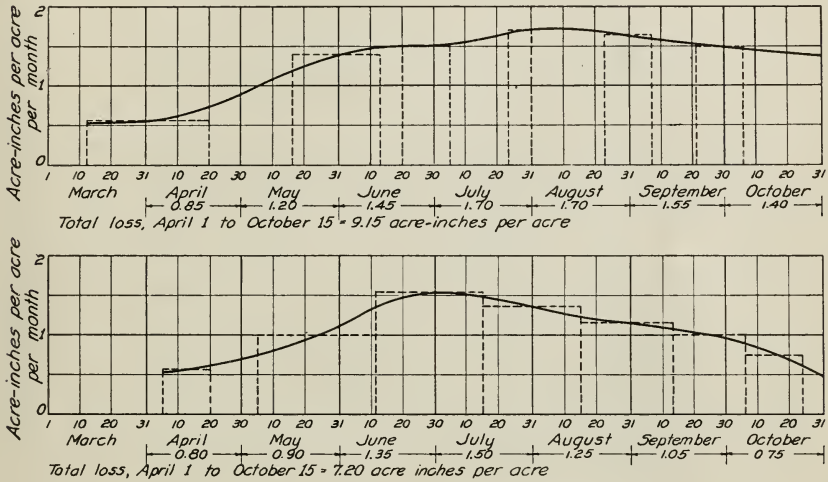


Fig. 15.—Top, probable seasonal use of water with a full supply of soil moisture available throughout the season, based on use during periods when ample moisture was available; bottom, the actual seasonal use with a deficiency in soil moisture during the latter part of the season. Treat avocado plot, season of 1927.

Assuming that the 'probable' curve represents the seasonal water requirement of this grove, a total of 9.15 acre-inches of available water in the soil per acre would have to be supplied by rainfall and irrigation to meet the needs of this grove. With 54 per cent of the root activity in the top foot of this shallow soil, irrigation water should be applied at the time the moisture content in the top foot reaches the wilting point. Since the soil has a field capacity of 12.5 per cent and a wilting point of 7.0 per cent, 1.7 acre-inches of water per acre would be available in it in the period between irrigations. The monthly uses, as obtained from the probable use-of-water curve, indicate that the first irrigation would be applied about June 1. If the average monthly requirement for the remainder of the season is 1.6 acre-inches per acre per month, and if 1.7 acre-inches per acre is available, the proper interval between irrigations would be 30 days, five irrigations being required during the season.

On a basis of 60 per cent efficiency, 3 acre-inches per acre should be provided for at each irrigation, making a total seasonal requirement of 15 acre-inches per acre.

At maturity, with 67 per cent of the soil mass moistened at each irrigation, the total seasonal requirement would be 17 acre-inches per acre, while with the whole soil mass moistened the requirement would be increased to 25 acre-inches per acre.

SUMMARY OF RESULTS, SEASON OF 1927

TABLE 39

MONTHLY USE OF WATER* BY SIX GROVES UNDER OBSERVATION IN SAN DIEGO COUNTY, APRIL 1 TO OCTOBER 15, 1927

Farm	Crop	Age of trees, years	Apr.	May	June	July	Aug.	Sept.	Oct.†	Total
			Acre-inches per acre							
Wilkins	Lemons	16	1.33	1.38	1.80	2.45	2.58	2.57	1.27	13.39
Treat	Lemons	13	0.70	0.80	1.05	1.25	1.20	0.90	0.37	6.27
Hinrichs	Valencia oranges	7	0.85	0.92	1.15	1.20	1.08	0.87	0.39	6.85
Red Mt., Plot *A*	Navel oranges	31	1.00	1.10	1.20	1.50	1.80	1.75	0.82	9.20
Red Mt., Plot *B*	Navel oranges	7	0.80	0.85	0.90	0.93	0.95	0.92	0.44	5.80
Treat	Avocados	13	0.85	1.20	1.45	1.70	1.70	1.55	0.70	9.15

* Taken from seasonal use-of-water curves. † October 1 to October 15 only.

Table 40 shows the apparent root development in the various soil types at depths to which soil samples were taken in the different groves. Here, as in 1926, the rate of soil-moisture loss at the various soil depths is taken as a measure of the root development at those depths.

TABLE 40

APPARENT ROOT DEVELOPMENT IN VARIOUS SOIL DEPTHS FOR THE VARIOUS ORCHARDS STUDIED

Farm	Crop	Soil type	Depth of soil, feet	Root activity, per cent*				
				1st foot	2nd foot	3rd foot	4th foot	5th foot
Wilkins	Lemons	Sierra sandy loam	4.0	33	31	24	12	.....
Treat	Lemons	Sierra sandy loam	2.5	63	31	6	.....	.....
Hinrichs	Lemons	Sierra sandy loam	4.0	47	24	17	12	.....
Red Mt. plot *A*	Oranges	Holland sandy loam	5.0	35	25	20	16	4
Red Mt. plot *B*	Oranges	Holland sandy loam	4.0	40	23	20	17	.....
Treat	Avocados	Sierra sandy loam	2.5	54	35	11	.....	.....

* Based on total seasonal moisture loss from each foot in depth.

TABLE 41

SUMMARY OF USE OF WATER AND ESTIMATED IRRIGATION REQUIREMENTS FOR SEVEN SAN DIEGO COUNTY GROVES, SEASON OF 1927

Grove	Location	Crop	Age of trees, years	Relative size of trees*	April 1 to Oct. 15, acre-inches per acre	Amount supplied by rainfall, inches	Amount supplied by irrigation, acre-inches per acre	Required number of irrigations	Average required depth of each irrigation, inches	Average interval between irrigations, days	Total seasonal requirement, acre-inches per acre	Estimated seasonal requirement of grove at maturity, under present irrigation practice, acre-inches per acre	Estimated requirement at maturity with 100 per cent of soil mass moistened at each irrigation, acre-inches per acre
Wilkins	Escondido	Lemons	16	100	13.4	4.0	9.4	3	6.25	45	18.75	18.5	18.5
Clemens	Fallbrook	Lemons	11	60	7.0	2.1	4.9	4	2.0	40	8.0	13.5	20.0
Treat	Vista	Lemons	13	76	6.3	1.6	4.7	4	2.0	35	8.0	10.5	16.0
Hinrichs	Escondido	Valencia oranges	7	40	6.8	2.5	4.3	3	2.5	45	7.5	18.0	27.0
Red Mt. Plot *A*	Fallbrook	Navel oranges	31	78	9.2	3.0	6.2	3	4.25	45	12.75	16.5	16.5
Red Mt. Plot *B*	Fallbrook	Navel oranges	7	36	5.8	2.35	3.45	3	2.25	45	6.75	18.5	18.5
Treat	Vista	Avocados	13	90	9.2	1.7	7.5	5	3.0	30	15.0	17.0	25.0

* Relative size is based on a comparison of averages of the outside areas of the trees included in each plot.

EFFICIENCY OF IRRIGATION

As previously stated, efficiency of irrigation is defined as the percentage of the water applied that is shown in soil-moisture increase in the soil mass occupied by the principal rooting system of the crop. Tables 42 and 43 show the results of a number of observations made during the irrigation seasons of 1926 and 1927.

The results contained in tables 42 and 43 show a wide variation in the efficiency of irrigation, ranging from a maximum of 73 per cent to a minimum of 26 per cent, and averaging 52 per cent, for the 40 observations made during the two years.

TABLE 42

EFFICIENCY OF IRRIGATION, SEASON OF 1926

Method of irrigation	Soil mass moistened, per cent	Water applied	Water accounted for	Per cent efficiency
		Acre-inches per acre per irrigation		
Furrow	....	2.32	1.51	65
	50	2.06	1.49	72
	50	2.02	1.19	59
	....	0.90	0.57	63
	50	2.50	1.42	57
	50	1.30	0.75	58
	50	1.14	0.62	54
	....	1.10	0.61	55
	40	1.86	1.06	57
	....	2.52	1.16	46
	60	2.84	1.22	43
	25	2.41	0.94	39
	20	2.20	0.66	30
Spray	....	2.36	1.47	62
	100	2.62	1.72	66
	100	1.95	1.20	61
Average				55.4

Under conditions characterized by rolling topography and where the furrow method of irrigation was used, low efficiencies generally resulted from excessive run-off from the ends of the furrow. Other losses include those from deep penetration at the heads of the furrows, the unavoidable losses due to evaporation from the water surface during irrigation, and those incurred in moistening the soil mulch. Where shallow depths of water are applied at frequent intervals, the evaporation from the water surface during irrigation and evaporation from the soil mulch may represent a major portion of the total.

As a result of the measurements and observations made during the two years, the conclusion is drawn that under existing conditions as found in the areas under observation, the average efficiency which may be expected under good irrigation practice is about 60 per cent.

TABLE 43

Efficiency of Irrigation, Season of 1927

Method of irrigation	Soil mass moistened, per cent	Water applied (Acre-inches per acre per irrigation)	Water accounted for (Acre-inches per acre per irrigation)	Per cent efficiency
Furrow	90	6.40	3.70	58
	100	6.40	3.84	60
	100	6.80	4.46	66
	64	2.49	1.67	67
	64	3.01	1.17	39
	67	2.74	1.23	45
	90	2.49	1.80	72
	90	3.01	2.20	73
	90	2.74	1.98	72
	40	1.68	0.54	32
	70	1.93	1.10	57
	69	3.27	1.00	31
	69	2.34	0.61	26
	65	2.17	0.92	42
	38	1.68	0.55	32
	67	1.93	1.28	66
	66	3.27	0.99	30
	66	2.34	1.05	45
	62	2.17	1.08	50
Spray	.....	4.28	1.50	35
	100	7.50	3.50	47
	.....	2.50	1.16	46
	100	5.00	2.82	56
	100	5.00	2.11	42
Average				49.6

CONCLUSIONS

1. The winter water requirement of citrus groves in northern San Diego County in which cover crops of vetch or grass and weeds are grown, varied from 8.6 acre-inches per acre to 12.0 acre-inches per acre, depending upon the size of the trees and condition of the cover crop.

2. In the areas of northern San Diego County covered by this report, normal rainfall **when properly distributed** is adequate to meet the winter needs of both trees and cover crops.

3. Periods of drought of more than six weeks' duration during the winter, even if preceded by heavy rains, will, under conditions of cover cropping, require an application of irrigation water.

4. Analysis of rainfall records at Escondido and Fallbrook shows, that because of deficiency in seasonal rainfall or lack of normal distribution, in at least three years out of ten, one winter irrigation, and in two years out of ten, two winter irrigations, should be provided to meet normal winter requirements of trees and cover crops.

5. With 60 per cent efficiency in irrigation and with 90 to 100 per cent of the soil mass moistened at each irrigation, mature citrus groves in the Escondido and Fallbrook areas have a net seasonal summer irrigation requirement of 18 acre-inches of water per acre. Similar groves in the Vista area under similar conditions require at least 15 acre-inches per acre. In fully mature groves where smaller quantities than these are available and where furrow irrigation is practiced, a correspondingly smaller percentage of the soil mass should be moistened at each irrigation.

6. Citrus groves, 6 to 8 years of age and 40 to 50 per cent of their probable ultimate size, will have a net seasonal summer water requirement of 6 to 8 acre-inches per acre.

7. In the Sierra and Holland sandy loams 4 to 6 feet deep, the interval between irrigations should not exceed 45 days. As the depth of soil becomes less, the interval should be shortened, soils of 2 to 3 feet in depth requiring irrigation every 30 to 35 days, with smaller amounts of water applied at each irrigation.

8. In properly laid out groves on rolling topography, and where care is used in the application of water, 60 per cent of the water delivered to the grove should be accounted for in soil-moisture increase in the soil mass occupied by the major rooting system of the trees.

9. As long as the soil moisture is above the wilting point, the moisture content has no measurable effect on the rate of moisture extraction; that is, moisture is as readily available when the moisture content is one-third or two-thirds of the way between field capacity and the wilting point as it is in the thoroughly moistened soil after irrigation.

10. In the experiments thus far completed, indications are that when the available moisture in the unirrigated portions of the soil has been exhausted, there is no apparent increase in the rate of extraction from the irrigated portions; and when the available moisture in the top foot of soil has been exhausted, there is no increase in the rate of extraction from the lower depths.

11. Some evidence was obtained from the Hinrichs grove at Escondido that the quantity of water used by citrus trees may be to some extent dependent on the percentage of soil mass moistened. While this is contrary to previously accepted principles, the evidence referred to seems to warrant further investigation, and this is being arranged for.

12. In mature citrus groves in soils 5 feet or more in depth, an average of not more than 5 per cent of the moisture extracted was taken from the fifth foot, the mature trees having a greater range of root activity than is found in the partly matured groves. In soils less than 3 feet in depth, 50 to 60 per cent of the root activity is in the top foot of soil.

13. Under the same soil conditions, a greater apparent moisture absorption by roots is found in the lower soil depths with avocados than is found with citrus.

ACKNOWLEDGMENTS

The authors of this bulletin wish to express their grateful appreciation for the hearty cooperation of the growers on whose property these investigations were conducted. They are especially grateful to the manager and directors of the Vista Irrigation District for furnishing office and laboratory space during the two years in which the field work was being carried on.

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